Dist. Oper (3)

MCDONNELL DOUGLAS TECHNICAL SERVICES CO.
HOUSTON
JM86

16915 El Camino Real, Suite 220, Houston, Texas 77058

22 October 1976
HAD-1.4-239

CR 151007

(NASA-CR-151007) NAVIGATION INPUT TO LEVEL C OFT NAVIGATION FUNCTIONAL SUBSYSTEM SOFTWARE REQUIREMENTS (RENDEZVOUS ONORBIT-2) (McDonnell-Douglas Astronautics) 523 p HC A22/MF A01 CSCL 22A G3/13 N77-11077, Unclas 54598

Subject: Contract No. NAS-9-14960, Task Order No. D0510, Task Assignments C, D, E, and G, Transmittal of Design Note No. 1.4-8-015

To: NASA/Lyndon B. Johnson Space Center
Attention: R. T. Savely/FM8
2101 Nasa Road 1
Houston, Texas 77058

Enclosure: (1) Navigation Input to Level C OFT Navigation Functional Subsystem Software Requirements (Rendezvous Onorbit-2)

1. Enclosure (1) presents the rendezvous (onorbit-2) navigation software design requirements for the Orbital Flight Test (OFT) phase of the Space Shuttle. This design note has been prepared in the format of a Functional Subsystem Software Requirements (FSSR) document, and contains not only the recently developed rendezvous design, but also the onorbit-1 requirements. Thus, the contents of this enclosure represent the most recent OFT navigation requirements for the orbit operations computer load. In addition, due to recent decisions to split documentation of OFT navigation requirements into three separate books (one per each computer load), the enclosed represents the first publication of the orbit operations FSSR book. This design note does not constitute an official track task FSSR input. The first such input is currently scheduled for 17 December 1976 (onorbit-1).

2. This letter partially fulfills a deliverable requirement of JSC/MDC Task Order D0510, Task Assignments C, D, E, and G.

W.E. Hayes

W. E. Hayes
Project Manager
Mission Planning, Mission Analysis and Software Formulation

ORIGINAL PAGE IS OF POOR QUALITY

DAL:pa

EC: See attached sheet

MCDONNELL DOUGLAS
CORPORATION

22 October 1976
HAD-1.4-239

Dees

Duncan

Ewell

Howard

Little

Lukaszewski

Pocklington

Spencer

Wedlake

Dugge

Hayes

Chamberlin

Subject: Contract No. NAS-9-14960, Task Order No. D0510, Task Assignments C, D, E, and G, Transmittal of Design Note No. 1.4-8-015

To: NASA/Lyndon B. Johnson Space Center
Attention: R. T. Savely/FM8
2101 Nasa Road 1
Houston, Texas 77058

Enclosure: (1) Navigation Input to Level C OFT Navigation Functional Subsystem Software Requirements (Rendezvous Onorbit-2)

1. Enclosure (1) presents the rendezvous (onorbit-2) navigation software design requirements for the Orbital Flight Test (OFT) phase of the Space Shuttle. This design note has been prepared in the format of a Functional Subsystem Software Requirements (FSSR) document, and contains not only the recently developed rendezvous design, but also the onorbit-1 requirements. Thus, the contents of this enclosure represent the most recent OFT navigation requirements for the orbit operations computer load. In addition, due to recent decisions to split documentation of OFT navigation requirements into three separate books (one per each computer load), the enclosed represents the first publication of the orbit operations FSSR book. This design note does not constitute an official track task FSSR input. The first such input is currently scheduled for 17 December 1976 (onorbit-1).

2. This letter partially fulfills a deliverable requirement of JSC/MDC Task Order D0510, Task Assignments C, D, E, and G.

W. E. Hayes
Project Manager
Mission Planning, Mission Analysis
and Software Formulation

ORIGINAL PAGE IS OF POOR QUALITY

DAL:pa

EC: See attached sheet

MCDONNELL DOUGLAS TECHNICAL SERVICES CO.
HOUSTON ASTRONAUTICS DIVISION

SPACE SHUTTLE ENGINEERING AND OPERATIONS SUPPORT

DESIGN NOTE NO. 1.4-8-015

NAVIGATION INPUT TO LEVEL C OFT NAVIGATION FUNCTIONAL SUBSYSTEM SOFTWARE REQUIREMENTS (RENDEZVOUS ~ ONORBIT-2)

MISSION PLANNING, MISSION ANALYSIS AND SOFTWARE FORMULATION

---

22 October 1976

This Design Note is Submitted to NASA Under Task Order No. D0510, Task Assignments C, D, E, and G, in Fulfillment of Contract NAS 9-14960.

PREPARED BY:

J.V. Dees
Task Manager C

L.M. Duncan
Engineer

J.J. Ewell
Task Manager G

M.L. Howard
Senior Engineer

M.J. Little
Engineer

D.A. Lukaszewski
Task Manager E

R.C. Pocklington
Task Manager D

J.J. Spencer
Senior Engineer

APPROVED BY:

W.E. Wedlake
Integration Manager
Orbiter Navigation Software

P.M. Dugge
Technical Manager
Mathematical Physics

W.E. Hayes
Project Manager
Mission Planning,
Mission Analysis,
Software Formulation

CONTENTS

CONTENTS

CONTENTS

CONTENTS

1.0 INTRODUCTION

This document provides Level C detailed navigation requirements for review prior to the 8 November 1976 onorbit-1 and onorbit-2 mode team meetings and the subsequent on-orbit operations computer load (i.e. the navigation software for the entire operational sequence 2, and operational sequence 8). The original intention was to issue only rendezvous - unique requirements, but, in the process of generating the rendezvous design, a substantial re-design was necessary for the onorbit-1 software. This, coupled with the recent decision to separate all navigation Level C requirements into three separate books per memory load resulted in the decision to document the entire orbit operations computer load, rather than just rendezvous - unique requirements.

The rendezvous (onorbit-2) requirements are based on revision to MDTSCO Transmittal Memo 1.4-MPB-323, First Data Dump - Rendezvous (onorbit-2) Navigation Software, dated 30 July 1976, suggested at two TELECON review sessions held on 20 and 26 August. The onorbit-1 (non-rendezvous) requirements are based on the July 1976 FSSR, modified by the 25 June 1976 FSSR input change page document, further modified by changes which came about during the rendezvous software design process, and finally modified by the ascent/

onorbit mode team meeting (August 2 through 6, 1976) decisions. All changes and FSSR section status are identified in the PHASE 4 A Status Log included in this section.

The following assumptions were used in the development of the Level C onorbit-2 (and revised onorbit-1) requirements, and thus represents the combined developmental phases 4 and 4A:

1. No onboard external data are processed during the non-rendezvous portion of operational sequence 2. One-way Doppler/TDRSS measurement incorporation is not currently planned for the OFT program.
2. The following external data will be processed during the rendezvous coast and TPF stationkeeping navigation phases (no external data will be processed during the rendezvous powered flight navigation phases):
   a. Rendezvous radar shaft angle, trunion angle, range, and range rate,
   b. Star tracker horizontal and vertical angles, and
   c. COAS (Crew Optical Alignment Sight) horizontal and vertical angles.
3. A nine-dimensional state vector is maintained during nonrendezvous portions of operational sequence 2 (three, position; three, velocity; and three, unmodeled acceleration biases).

4. The state vector maintained during rendezvous coast, rendezvous powered flight, and TPF stationkeeping navigation phases is composed of 19 elements/

   1-3 Orbiter position (Aries mean of 1950)

   4-6 Orbiter velocity (Aries mean of 1950)

   7-9 Orbiter unmodelled acceleration biases (body coordinate system)

   10-12 Target position (Aries mean of 1950)

   13-15 Target velocity (Aries mean of 1950)

   16-19 Rendezvous tracker biases (sensor coordinate systems)

5. Prestored tables of nominal vehicle attitude, nominal vent magnitude and body-relative thrust directions, nominal RCS uncoupled thrust magnitudes and body-relative directions, and vehicle/payload area configuration are required for acceleration models.

6. The IMU SOP provides an estimate of the total accumulated IMU velocity at the time of a data snap, in the presence of commfaults.

7. All operational sequence 2 (and 8) floating point variables are assumed to be in double precision.

8. TPF stationkeeping phase includes braking and LOS control phases.

9. External measurement data are selected and processed mutually exclusive on an instrument basis, with the exception of rendezvous radar range and range-rate which

may be processed with COAS, star tracker, or rendezvous radar angles. The DIP (display interface processor) will insure this by activiting the navigation sensor selection "ENABLE" flag for only the most recently crew-selected instrument.

10. All rendezvous tracker bias variances are propagated as exponentially correlated random variables.
11. A 19x19 covariance matrix of Aries mean of 1950 position and velocity (orbiter and target), of body-fixed acceleration bias errors, and of at most four rendezvous tracker (instrument) biases, is propagated during rendezvous coast, rendezvous powered flight, and TPF stationkeeping navigation phases. A 9x9 covariance matrix of Aries mean of 1950 position and velocity (orbiter, only), and of three body-fixed acceleration bias errors, is propagated during onorbit coast and onorbit powered flight navigation phases.
12. Use of sensed velocity in the navigation state propagator is triggered by entrance into the onorbit or rendezvous powered flight navigation phases (ignition time minus TBD seconds, event-68) and a prestored sensed acceleration threshold. Use of sensed velocity during TPS/stationkeeping is triggered by entrance into that major mode (MM 213) and by a prestored sensed acceleration threshold.
13. External measurement data processing shall be inhibited

during rendezvous powered flight navigation phases. Inhibiting shall commence at ignition time minus TBD seconds. This event is independent of the event (#68) to begin the rendezvous navigation phase, itself.

14. Backward and forward integration capability is provided for state prediction and propagation.
15. Prestored nominal attitude time lines are used for prediction, and current AAM attitude is used for propagation.
16. The precision state prediction function has accuracy comparable to that of the precision state propagation function, and has the option of being executed in a faster (but less accurate) conic mode.
17. Acceleration models include attitude-dependent drag and venting, Earth gravity, and uncoupled (RCS) thrusting effects.
18. A one-state vector configuration applies during all navigation phases in operational sequence 2 (and 8).
19. The acceleration due to lift force is assumed to be negligible in the atmospheric drag acceleration model.
20. An automatic inflight update capability will be provided by which the ground can uplink either an orbiter or a target state vector (M1950) and associated time tag, during any navigation phase (rendezvous or non-rendezvous). The following additional assumptions apply to this capability:

    a. The ground shall uplink one vehicle state (3 position,

3 velocity, associated time tag, and vehicle ID) at a time.

b. The onboard software receiving this data (ground uplink processor) will set the DO_AUTO_UPDATE flag to "ON", test the vehicle ID to determine if the uplinked data pertains to orbiter or target, and set up one of the following two variable sets, depending on the results of this test

$$\left\{\begin{array}{l} \underline{R}\text{\_GND} \\ \underline{V}\text{\_GND} \\ \text{T\_GND} \\ \text{OV\_UPLINK = ON} \end{array}\right\} \begin{array}{l}\text{Orbiter}\\ \text{Uplink}\end{array} \quad \text{OR} \quad \left\{\begin{array}{l} \underline{R}\text{\_TV\_GND} \\ \underline{V}\text{\_TV\_GND} \\ \text{T\_TV\_GND} \\ \text{TV\_UPLINK = ON} \end{array}\right\} \begin{array}{l}\text{Target}\\ \text{Uplink}\end{array}$$

c. The navigation software has the capability of re-initializing the orbiter and/or target state vectors (and associated covariance matrix) in a single navigation cycle.

d. If a target vector is uplinked during a non-rendezvous navigation phase, it is stored for eventual use in a rendezvous phase.

e. Whenever an orbiter or target state vector is re-initialized because of a ground update, all correlations between orbiter and target vehicle position and velocity errors are zeroed. The respective vehicle (6x6) position/velocity submatrices are re-initialized using prestored UVW values (or uplinked) UVW values. All

in-plane correlation terms, and a single out-of-plane correlation term is included in this re-initialization.

21. Propagation of orbiter position and velocity vectors will be performed by use of the precision integration scheme (during onorbit and rendezvous coasting flight navigation phases), and by use of the super-G integration scheme during onorbit and rendezvous powered flight navigation phases and during the TPF stationkeeping navigation phase. Propagation of the target position and velocity vectors will be performed by use of the precision integration scheme in <u>all</u> rendezvous-related navigation phases (coasting, powered, and TPF stationkeeping).

22. Upon entry into a rendezvous-related navigation phase from a non-rendezvous-related navigation phase, or, from outside of OPS-2, the target state vector will be initialized according to one of the following four options:

    a. Set to ground uplinked value (predicted to current time),

    b. Set to last onboard estimate from previous rendezvous phase (predicted to current time),

    c. Set to equal to current orbiter state, or

    d. Set to pre-mission stored values (predicted to current time).

1-7

Option c., above, is included to handle the current OFT rendezvous sequence, in which target and orbiter actually begin in a near stationkeeping configuration, separate, then rendezvous.

23. If the sensor (including IMU) SOP's are not in the same GPC as the navigation filter software:

    a. Data and time tag must be preserved as a pair,

    b. ICC (inter computer communication) transmission of data must be pairwise, and

    c. ICC transmission rate must be fast enough such that the data time tag and "current time: (in NAV GPC) differ by no more than TBD seconds.

    If the sensor SOP's and navigation filter reside in the same GPC:

    a. Data must be time tagged, and

    b. Data must be no more than TBD seconds.

The next FSSR input to the onorbit-1 (non-rendezvous, phase 4) requirements will be on 17 December 1976.

RENDEZVOUS SOFTWARE CHANGE LOG (22 October 1976)

SECTION NO.	SECTION TITLE	DESCRIPTION OF CHANGE
1.0	INTRODUCTION	Revise list of assumptions to include recent rendezvous design, 25 June 1976 onorbit-1 FSSR input change-page document changes, and requirements for OPS-8 and checkpoint resulting from the recent ascent/onorbit mode team meeting; add page change notice
2.0	APPLICABLE DOCUMENTS	(to be provided)
3.0	OVERVIEW	(to be provided)
4.0	DETAILED REQUIREMENTS	Minor word changes to reflect addition of PHASE 4A requirements (rendezvous)
4.1	Navigation and User Parameter Sequencer Principal Functions	Minor word changes to reflect single computer load FSSR
4.1.1	Onorbit/Rendezvous Navigation Sequencer	Modifications to include rendezvous requirements; slight logic re-structuring and initializing procedure to take advantage of software commonality between onorbit and rendezvous functions; incorporate covariance re-initialization module, for use by both onorbit & rendezvous software for sequencer initialization and ground updates; add logic to operate during OPS-8; and initialization into OPS-2 from a CHECKPOINT: section renumbered
4.1.2	Onorbit/Rendezvous User Parameter Processing Sequencer	Section renumbered; update to provide scheduling requirements for onorbit user parameter calculations and to reflect changes in scheduling require-

SECTION NO.	SECTION TITLE	DESCRIPTION OF CHANGE
		ments for onorbit user parameter state propagation
4.2	Subfunctions Common to Several Navigation Principal Functions	Change title of section to: "Subfunctions Common to Several Navigation Functions". Change wording to allow requirements to be written in this section which are 1. common to two or more navagation principal functions, or 2. common to two or more navigation subfunctions (either within the same principal function, or from different principal functions)
4.2.1	State Propagation	Minor word changes reflections outline change to single onorbit-operations computer load FSSR
4.2.1.1	IMU Data Snap	Minor word changes reflecting outline change to a single orbit operations computer load FSSR (single-string snap only)
4.2.1.2	Acceleration Models	Minor word changes reflecting outline change to a single orbit operations computer load FSSR
4.2.1.2.1 4.2.1.2.2 4.2.1.2.3	Gravity Drag Venting and Uncoupled RCS Thrusting	These are new sections added to the "common subfunction" section, since they are common to both onorbit navigation and rendezvous navigation principal functions... previously documented directly under onorbit navigation state propagation; also fix error in attitude model
4.2.1.3	Integration of State Equations of Motion	Minor word changes reflecting outline change to a single orbit operations load FSSR
4.2.1.3.1	Super-g	Section added as per outline change, and to be common element... for onorbit and rendezvous navigation state propagation.

SECTION NO.	SECTION TITLE	DESCRIPTION OF CHANGE
4.2.1.3.2	Precision	Correct errors, bring requirements up to date based on 25 June 1976 onorbit-1 FSSR, and recent rendezvous design
4.2.2	Covariance Matrix Propagation	New section describing revised mean-conic-partial techique for propagating covariance matrix for both onorbit-1 and rendezvous
4.2.3	State Vector Interpolation	New section describing rendezvous measurement requirements for state vector interpolation.
4.2.4	State and Covariance Measurement Incorporation (Kalman Filter)	New section describing revised Kalman filter equations for use during rendezvous navigation
4.2.5	Ground Updates (auto inflight)	New section describing revised auto inflight update requirements for both orbiter and/or target vector uplinks
4.2.6	Angle Measurement Partials	New section describing common requirements to several rendezvous navigation subfunctions dealing with Kalman filter angle measurement observation partials
4.2.7	Conic Solution (F and G Series)	New section, documenting common requirements for conic (orbital 2-body problem) solutions used in . precision state propagation/prediction (Pines Method), . mean-conic partials technique (currently proposed for transition matrix generation associated with onorbit & rendezvous covariance matrix propagation, and . rendezvous state vector interpolation
4.2.8	Position-Velocity Submatrix of State Transition Matrix	New section, documenting onorbit/rendezvous requirements for computing transition matrix, for use in covariance matrix propagation (note: this technique is proposed to replace old onorbit-1 technique), and involves use of "mean conic partials"

SECTION NO.	SECTION TITLE	DESCRIPTION OF CHANGE
4.2.9	Covariance Initialization	New section describing requirements for initializing a 6X6 covariance matrix from prestored UVW standard deviations and correlation coefficients ... used for both ground updates and sequencer initializations
4.3	Navigation Processing Principal Functions	Minor word changes reflecting outline change to a single orbit operations load FSSR
4.3.1	Onorbit Navigation	Minor word changes to describe capability to update target state vector during onorbit navigation add principal function I/O table
4.3.1.1	Onorbit Control	No changes required except for section number; included for document completeness
4.3.1.2	State and Covariance Setup	Make consistent with latest onorbit/rendezvous design (i.e, allow uplink of <u>either</u> orbiter or target state)
4.3.1.3	State Propagation	Make consistent with latest onorbit/rendezvous design; refer to "common subfunction sections" for detailed requirements of tasks: . IMU data snap . acceleration models . integration of equations of motion . propagation of biases
4.3.1.4	Covariance Matrix Propagation	Changes to make consistent with recent rendezvous design
4.3.2	Rendezvous Navigation	New section describing overall subfunctions under the rendezvous navigation principal function
4.3.2.1	Rendezvous Control	New section identifying navigation executive logic during rendezvous & TPF stationkeeping phases
4.3.2.2	External Sensor Data Snap	New section describing data snap requirements during rendezvous navigation P.F. operation (rendezvous radar, star tracker, and COAS)

SECTION NO.	SECTION TITLE	DESCRIPTION OF CHANGE
4.3.2.3	Sensor Measurement Selection	New section describing sensor selection of angles data (star tracker, COAS, & rendezvous radar) independent of radar range & range rate
4.3.2.4	State and Covariance Setup	New section header describing reconfiguration of state and covariance because of measurement reconfiguration or ground update for rendezvous
4.3.2.4.1	Measurement Reconfiguration	New section describing requirements for state and covariance reinitialization as a result of a new sensor measurement configuration
4.3.2.4.2	Auto In-Flight Update	New section describing requirements for state and covariance reinitialization as a result of either orbiter and/or target ground update during rendezvous
4.3.2.5	State Propagation	New section describing requirements for orbiter & target state vector propagation during powered and coasting flight arcs of rendezvous
4.3.2.6	Covariance Matrix Propagation	New section describing requirements for powered and coasting flight covariance matrix propagation during rendezvous navigation phases
4.3.2.7	State and Covariance Measurement Incorporation	New section header describing requirements for state and covariance filter updates during rendezvous
4.3.2.7.1	Rendezvous Radar Range	New section requirements for calculation of Kalman filter partial vector & residual for rendezvous radar range measurement
4.3.2.7.2	Rendezvous Radar Range-Rate	New section requirements for calculations of Kalman filter partial vector & residual for rendezvous radar range-rate measurement

SECTION NO.	SECTION TITLE	DESCRIPTION OF CHANGE
4.3.2.7.3	Rendezvous Radar Shaft Angle	New section requirements for calculation of Kalman filter partial vector & residual for rendezvous radar shaft angle measurement
4.3.2.7.4	Rendezvous Radar Trunion Angle	New section requirements for calculation of Kalman filter partial vector & residual for rendezvous radar trunion angle measurment
4.3.2.7.5	Star Tracker Horizontal Angle	New section requirements for calculation of Kalman filter partial vector & residual for star tracker horizontal angle measurement
4.3.2.7.6	Star Tracker Vertical Angle	New section requirements for calculation of Kalman filter partial vector & residual star tracker vertical angle measurement
4.3.2.7.7	COAS Horizontal Angle	New section requirements for calculation of Kalman filter partial vector & residual for COAS horizontal angle measurement
4.3.2.7.8	COAS Vertical Angle	New section requirements for calculation of the Kalman filter partial vector & residual for COAS vertical angle measurement
4.3.2.8	Measurement Processing Statistics	New section; modification of entry measurement processing statistics requirements to satisfy unique onorbit display requirements; include "target confirm" logic (previously done in ST SOP).
4.4	Subfunctions Common to Several Navigation-Related Principal Functions (Coordinate Transformations)	(this header and all subsections 4.4.1 through 4.4.9 will be provided at a later date)
4.5	General Requirement Principal Functions	Minor modifications (new FSSR structure)

SECTION NO.	SECTION TITLE	DESCRIPTION OF CHANGE
4.5.1	Site Lookup	(to be provided)
4.5.2	Onorbit Precision State Prediction	Correct errors; and generally bring requirements up to date based on 25 June 1976 onorbit-1 FSSR input, and recent acceleration model changes
4.5.3 4.5.3.1 4.5.3.2	Star Tracker SOP Ephemerides Solar Ephemeris Lunar Ephemeris	(to be provided)
4.6	User Parameter Processing Principal Function (onorbit)	New section describing subfunctions within the onorbit user parameter processing principal function
4.6.1	User Parameter State Propagation	New section describing requirements for user parameter state propagation as per recent rendezvous design; change integration method from fixed - G to average -G as per recent ascent/onorbit mode team discussion
4.6.2	Onorbit User Parameter Calculations	New section describing CRT display requirements for onorbit and rendezvous
4.7	Specialist Functions Navigation Support Formulations	(to be provided)
4.8	I-Load Requirements	(to be provided...will contain essence of old "CONSTANTS" section)
4.9	Down List Requirements	(to be provided)
Appendix A	Navigation Variable Names & Descriptions	Revise complete variable list for orbit-operations computer load
Appendix B	Navigation Sequencer Principal Functions and Navigation Processing Principal Function Flow Charts	Revise table of contents to contain list of latest onorbit and rendezvous flow charts: include all orbit operations load flow charts

SECTION NO.	SECTION TITLE	DESCRIPTION OF CHANGE
Appendix C	General Requirement Principal Function Flow Charts	Revise table of contents to contain list of latest orbit and rendezvous flow charts; include only flow chars and variable names for predictor software ... coordinate system flow charts and definitions to be provided later
Appendix D	User Parameter Flow Charts, Variable Names, and Descriptions	Provide revised table of contents variable list and flow charts for orbit operations load ... in the area of user parameter processing functions.
Appendix E	Specialist Function Navigation Support Flow Charts, Variable Names, and Descriptions	(to be provided)

4.0 DETAILED REQUIREMENTS

The various subsections of this section specify the detailed requirements for the Shuttle navigation system flight software package. This document contains OFT detailed requirements for navigation and user parameter processing principal functions for the orbit operations computer load (on-orbit and rendezvous), operational sequence 2. In addition, requirements dealing with navigation software functions during operational sequence 8 and in association with checkpoint storage and retreival are also addressed.

When viewed in the larger context of the total shuttle flight software, the navigation software package documented herein is, itself, a modular system whose function is to supply various parameters required by other major modular systems such as guidance, displays, flight control, and others. The requirements placed upon the navigation system by these various users often play a large role in determining the design structure and cyclic rate structure of the navigation system. The required interfaces between the navigation system and the other major software systems that use navigation system data are presented in the Level B CPDS document which controls all the interfaces between principal functions.

4.1 NAVIGATION AND USER PARAMETER SEQUENCER PRINCIPAL FUNCTIONS

The sequencer principal functions shall initialize and sequence the proper navigation and user parameter principal functions to meet navigation and user requirements. For OFT, there shall be one navigation sequencer principal function and one user parameter sequencer principal function that control navigation and user parameter principal functions during operational sequence 2 (orbit operations computer load).

navigation sequencer: on-orbit/rendezvous navigation sequencer

user parameter sequencer: on-orbit/rendezvous user parameter processing sequencer

4.1.1 Onorbit/Rendezvous Navigation Sequencer

The onorbit/rendezvous navigation sequencer principal function shall initialize and sequence the onorbit navigation and rendezvous navigation principal functions during operational sequence 2 (ops-2), while the following major modes are active:

MM 201, orbit coast

MM 202, (orbit coast) maneuver exec.

MM 211, rndz. nav.

MM 212, (rndz. nav.) maneuver exec.

MM 213, TPF stationkeeping

The onorbit/rendezvous navigation sequencer principal function shall also initialize and sequence the onorbit navigation principal function during operational sequence 8 (ops-8, orbital operation checkout).

Detailed requirements for each navigation processing principal function are identified in the specific principal function description sections (4.3.1. and 4.3.2). Cues for performing the proper navigation initialization and sequencing during ops-2 and ops-8 are defined in the Level B-GN&C CPDS. The particular events and resulting navigation software actions pertaining to the onorbit/rendezvous navigation sequencer principal function are shown in Table 4.1.1-1. Dynamic parameter input/output data flow between the onorbit/rendezvous

navigation sequencer principal function and other principal functions is shown in Tables 4.1.1-2 and 4.1.1-3.

TABLE 4.1.1-1 - ONORBIT/RENDEZVOUS NAVIGATION SEQUENCER EVENTS

EVENT NUMBER	EVENT NAME	NAVIGATION CRITERIA	NAVIGATION ACTION
60	transition to MM 201 from MM 107 (ops - 1)	"ops 201 pro"	Call: Ops_2_or_8 INITIALIZE Call: Onorbit_COVINIT_UVW Set: REND_NAV_FLAG = OFF, USE_IMU_DATA=OFF Signal: OPS_2_OR_8_INITIALIZE COMPLETE Set: PWRD_FLT_NAV = OFF Schedule: NAV_ONORBIT; repeat every DT_ONORBIT_NAV
60A	transition to MM 201 from GN&C ops-8	"ops 201 pro"	Call: OPS_2_OR_8_INITIALIZE Call: ONORBIT_COVINIT Set: REND_NAV_FLAG = OFF, USE_IMU_DATA = OFF Signal: OPS_2_OR_8_INITIALIZE COMPLETE Set: PWRD_FLT_NAV-= OFF Schedule: NAV_ONORBIT; repeat every DT_ONORBIT_NAV
60B	transition to GN&C ops-8 from MM 201 TERMINATE OPS-2	(refer to VU, level B CPDS)	Store selected parameters in protected memory locations for use by ops-8-or ops-3 navigation sequencer principal functions.

ORIGINAL PAGE IS OF POOR QUALITY

TABLE 4.1.1-1 - ONORBIT/RENDEZVOUS NAVIGATION SEQUENCER EVENTS

EVENT NUMBER	EVENT NAME	NAVIGATION CRITERIA	NAVIGATION ACTION
61	transition to MM 201 from MM301 (ops 3)	"ops 201 pro"	(same as for event #60A)
64	transition to MM 211 from MM 201	"ops 211 pro"	Cancel: NAV_ONORBIT Call: TARGET_NAV_INIT Set: USE_IMU_DATA = OFF PWRD_FLT_NAV = OFF USE_MEAS_DATA = ON TARG_VEC_AVAIL = ON Execute: DISPLAY_COUNT_INIT (CODE) Schedule: NAV_RENDEZVOUS; repeat every DT_REND_NAV
65	transition to MM 201 from MM 211	"ops 201 pro"	Cancel: NAV_RENDEZVOUS Set: REND_NAV_FLAG = OFF T_TV = T_CURRENT_FILT USE_IMU_DATA = OFF PWRD_FLT_NAV = OFF Schedule: NAV_ONORBIT; repeat every DT_ONORBIT_NAV

TABLE 4.1.1-1 - ONORBIT/RENDEZVOUS NAVIGATION SEQUENCER EVENTS

EVENT NUMBER	EVENT NAME	NAVIGATION CRITERIA	NAVIGATION ACTION
66	transition to MM 213 from MM 201	"ops 213 pro"	Cancel: NAV_ONORBIT Call: TARGET_NAV_INIT Set: PWRD_FLT_NAV = ON USE_MEAS_DATA = ON TARGET_VEC_AVAIL = ON Schedule: NAV_RENDEZVOUS; repeat every DT_REND_TPF_NAV
68	initiate powered flight navigation	TB7 y(sec.) (y seconds prior to a burn	if in rendezvous powered flight navigation phase (i.e., if REND_NAV_FLAG = ON) Cancel: NAV_RENDEZVOUS Set: PWRD_FLT_NAV = ON Schedule: NAV_RENDEZVOUS; repeat every DT_REND_PWRD_FLT if in onorbit powered flight navigation phase (i.e., REND_NAV_FLAG = OFF):
			Cancel: NAV_ONORBIT Set: PWRD_FLT_NAV = ON Schedule: NAV_ONORBIT; repeat every DT_ONORBIT_PWRD_FLT

TABLE 4.1.1-1 - ONORBIT/RENDEZVOUS NAVIGATION SEQUENCER EVENTS

EVENT NUMBER	EVENT NAME	NAVIGATION CRITERIA	NAVIGATION ACTION
73	transition to MM 201 from MM 202	"ops 201 pro"	Cancel: NAV_ONORBIT Set: USE_IMU_DATA = OFF PWRD_FLT_NAV = OFF Schedule: NAV_ONORBIT; repeat every DT_ONORBIT_NAV
74	transition to MM 211 from MM 107 (ops-1)	"ops 211 pro"	Call: OPS_2_OR_8_INITIALIZE Call: ONORBIT_COVINIT_UVW Call: TARGET_NAV_INIT Set: USE_IMU_DATA = OFF Signal: OPS_2_OR_8INITIALIZE COMPLETE Set: PWRD_FLT_NAV = OFF TARG_VEC_AVAIL = ON Execute: DISPLAY_COUNT_INIT (CODE) Schedule: NAV_RENDEZVOUS; repeat every DT_REND_NAV
78	transition to MM 211 from MM 212	"ops 211 pro"	Cancel: NAV_RENDEZVOUS Set: USE_IMU_DATA = OFF PWRD_FLT_NAV = OFF USE_MEAS_DATA = ON TARG_VEC_AVAIL = ON Execute: DISPLAY_COUNT_INIT (CODE) Schedule: NAV_RENDEZVOUS; repeat every DT_REND_NAV

TABLE 4.1.1-1 - ONORBIT/RENDEZVOUS NAVIGATION SEQUENCER EVENTS

EVENT NUMBER	EVENT NAME	NAVIGATION CRITERIA	NAVIGATION ACTION
79	transition to MM 213 from MM 212	"ops 213 pro:	Cancel: NAV_RENDEZVOUS Set: PWRD_FLT_NAV = ON USE_MEAS_DATA = ON TARG_VEC_AVAIL = ON Schedule: NAV_RENDEZVOUS; repeat every DT_REND_TPF_NAV
80	transition to MM 201 from MM 213	"ops 201 pro"	(same as for event #65)
81	Checkpoint complete (entry into MM 201 from ops-0)	Checkpoint complete and successful	Execute: CHECKPOINT_INIT (CODE) Call: OPS-2-OR_8_INITIALIZE Call: ONORBIT_COVINIT_UVW Set: REND_NAV_FLAG = OFF, USE_IMU_DATA = OFF Signal: OPS_2-OR_8_INITIALIZE COMPLETE Set: PWRD_FLT_NAV = OFF Schedule: NAV_ONORBIT; repeat every DT_ONORBIT_NAV
82	transition to MM 213 from MM 211	"ops 213 pro:	(same as for event #79)

TABLE 4.1.1-1 - ONORBIT/RENDEZVOUS NAVIGATION SEQUENCER EVENTS

EVENT NUMBER	EVENT NAME	NAVIGATION CRITERIA	NAVIGATION ACTION
E1	transition to MM 301 from MM 201 TERMINATE OPS-2	"ops 301 pro"	(same as for event #60B)
(TBD)	begin inhibiting incorporation of external measurement	TB7 (sec.) (x seconds prior to a burn)	Set: USE_MEAS_DATA = OFF test to see whether event #68 has occurred, and take appropriate action (see above table entry)... both event #68 and this TBD event may occur simultaneously
THE FOLLOWING EVENTS PERTAIN TO SEQUENCER FUNCTIONS DURING OPS-8			
50	transition to GN&C ops-8 from MM 106 (ops-1)	(refer to VU level B CPDS)	Call: OPS_2OR_8INITIALIZE Call: ONORBIT_COVINIT_UVW Set: USE_IMU_DATA = OFF Signal: OPS_2_OR_8_INITIALIZE COMPLETE Set: REND_NAV_FLAG = OFF PWRD_FLT_NAV = OFF Schedule: NAV_ONORBIT; repeat every DT_ONORBIT_NAV
60A	transition to MM 201 from GN&C ops-8 TERMINATE OPS-8	"ops 201 pro"	store selected parameters in protected memory locations for use by ops-2 navigation sequencer initialization functions.

TABLE 4.1.1-1 - ONORBIT/RENDEZVOUS NAVIGATION SEQUENCER EVENTS

EVENT NUMBER	EVENT NAME	NAVIGATION CRITERIA	NAVIGATION ACTION
60B	transition to GN&C ops-8 from MM 201 (ops-2)	(refer to VU level B CPDS)	Call: OPS_2OR_8_INITIALIZE Call: ONORBIT_COVINIT_UVW Set: USE_IMU_DATA = OFF Signal: OPS_2_OR_8_INITIALIZE COMPLETE Set: REND_NAV_FLAG = OFF PWRD_FLT_NAV = OFF Schedule: NAV_ONORBIT; repeat every DT_ONORBIT_NAV

TABLE 4.1.1-2: ONORBIT/RENDEZVOUS NAVIGATION SEQUENCER PRINCIPAL FUNCTION INPUT LIST

LEVEL B MNEMON	LEVEL C FSSR VARIABLE NAME	EXTERNAL PRINCIPAL FUNCTION SOURCE	INTERNAL SUBFUNCTION DESTINATION (SUBFUNCTIONS WITHIN THIS PRINCIPAL FUNCTION WHICH UTILIZE THE VARIABLE)	
			SUBFUNCTION * NAME	SUBFUNCTION INPUT TABLE
	R_FILT_INIT V_FILT_INIT	. Deorbit Lndg NAV Seq. . ASC NAV Seq . Orb/Rnd NAV Seq(Ops-8)	- -	4.1.1 - 4
	V_LAST_FILT_INIT T_LAST_FILT_INIT	. IMU RM . Deorbit Lndg NAV Seq . ASC NAV Seq . Orb/Rnd NAV Seq (Ops-8)	-	4.1.1 - 4
	E_INIT	. Deorbit Lndg NAV Seq . Orb/Rnd NAV Seq (Ops-8)	-	4.1.1 - 4
TBD	TARG_VEC_AVAIL R_TV V_TV T_TV	. Onorbit Navigation . REND Navigation	-	4.1.1-4
	T_CURRENT_FILT	. REND Navigation	-	4.1.1 - 4
	R_CHECK_PT V_CHECK_PT T_CHECK_PT	. CHECKPOINT SPEC FCN	-	4.1.1 - 4

* THIS PRINCIPAL FUNCTION CONTAINS NO SUB-FUNCTIONS

TABLE 4.1.1-3: ONORBIT/RENDEZVOUS NAVIGATION SEQUENCER PRINCIPAL FUNCTION OUTPUT LIST

LEVEL B MNEMON	LEVEL C FSSR VARIABLE NAME	EXTERNAL PRINCIPAL FUNCTION SOURCE	INTERNAL SUBFUNCTION DESTINATION (SUBFUNCTIONS WITHIN THIS PRINCIPAL FUNCTION WHICH UTILIZE THE VARIABLE)	
			SUBFUNCTION NAME	SUBFUNCTION INPUT TABLE
TBD	OPS 2 Or 8 Initialize Comp.	MSC	-	4.1.1-5
	R FILT V FILT V LAST FILT T LAST FILT E REND NAV FLAG PWRD FLT NAV SQR-EMU C MN AN S MN AN C MX AN S MX AN TOT ACC VENT THRUST BIAS	. Onorbit Navigation . Rendezvous Navigation	- -	4.1.1 - 5
	USE-MEAS-DATA R TV V TV G TV	. Rendezvous Navigation	-	4.1.1 - 5

* THIS PRINCIPAL FUNCTION CONTAINS NO SUB-FUNCTIONS

TABLE 4.1.1-3: ONORBIT/RENDEZVOUS NAVIGATION SEQUENCER PRINCIPAL FUNCTION OUTPUT LIST

LEVEL B MNEMON	LEVEL C FSSR VARIABLE NAME	EXTERNAL PRINCIPAL FUNCTION SOURCE	INTERNAL SUBFUNCTION DESTINATION (SUBFUNCTIONS WITHIN THIS PRINCIPAL FUNCTION WHICH UTILIZE THE VARIABLE)	
			SUBFUNCTION NAME	SUBFUNCTION INPUT TABLE
	N_ACCEPT N_REJECT SEQ_ACCEPT SEQ_REJECT	. Rendezvous Navigation	-	4.1.1 - 5
	USE_IMU_DATA	. Onorbit Navigation . Rendezvous Navigation . Onorbit USER PARAM PROC	-	4.1.1 - 5
TBD	R_RESET V_RESET V_IMU_RESET T_RESET FILT_UPDATE R_TV_RESET V_TV_RESET	. Onorbit USER PARAM PROC	-	4.1.1 - 5
	R_FILT_INIT V_FILT_INIT V_LAST_FILT_INIT T_LAST_FILT_INIT	. Deorbit Lndg NAV SEQ . Orb/Rnd NAV SEQ (Ops-8)	-	4.1.1 - 5
	E_INIT			

* THIS PRINCIPAL FUNCTION CONTAINS NO SUB-FUNCTIONS

A. Detailed requirements. For OFT orbital operations (ops_2 and ops_8), navigation requirements can be divided into five navigation phases: onorbit coast, onorbit powered flight, rendezvous coast, rendezvous powered flight, and TPF stationkeeping.

1. Onorbit coast navigation phase - This phase shall use the onorbit navigation principal function and shall be active during operation of major mode 201, and during operation of the orbital checkout operational sequence (ops-8). The onorbit coast navigation phase shall begin in one of the following ways:

- Entry into MM 201 from ops-3 or ops-8 (events 61 or 60A, respectively,
- Entry into MM 201 from ops-1 or ops-0, via checkpoint (events 60 or 81, respectively,
- Entry into MM 201 from MM 202 (event 73),
- Entry into MM 201 from MM 211 or MM 213 (events 65 or 80, respectively),
- Entry into GN&C ops-8 from ops-1 (event 50), or
- Entry into GN&C ops-8 from ops-2, MM 201, event 60B)

If the onorbit coast navigation phase is begun by entry into MM 201 from ops-3 or ops-8 (events 61 or 60A, respectively), the onorbit/rendezvous navigation sequencer principal function shall provide the capability to initialize the orbiter state vector, covariance matrix, and other

required navigation parameters on the basis of prestored computer locations unaffected by the computer program memory load reconfiguration. The following sequence should be followed:

1.1.1 - initialize orbiter position and velocity vectors and time tag

R_FILT = R_FILT_INIT

V_FILT = V_FILT_INIT

T_LAST_FILT = T_LAST_FILT_INIT

1.1.2 - initialize accumulated IMU velocity

V_LAST_FILT = V_LAST_FILT_INIT

1.1.3 - initialize those parameters required by the user parameter state propagation subfunction (section 4.6.1).

R_RESET = R_FILT_INIT

V_RESET = V_FILT_INIT

V_IMU_RESET = V_LAST_FILT_INIT

T_RESET = T_LAST_FILT_INIT

FILT_UPDATE = ON

1.1.4 - initialize other parameters as required for the onorbit navigation principal function

B = 0

VENT_THRUST_BIAS = 0.

SQR_EMU = SQRT (EARTH_MU)

C_MX_AN = COS (MAX_DENS_ANGLE)

S_MX_AN = SIN (MAX_DENS_ANGLE)

C_MN_AN = COS (MIN_DENS_ANGLE)

S_MN_AN = SIN (MIN_DENS_ANGLE)

1.1.5 - zero the total 19 x 19 dimensional covariance matrix

$$E_{1\text{ to }19,\ 1\text{ to }19} = 0$$

1.1.6 - initialize the diagonal elements of the covariance matrix pertaining to unmodeled acceleration biases, to premission constants

$$E_{I,I} = \text{COV\_ACCEL\_BODY\_INIT}_{I-6}$$

for I = 7 to 9

1.1.7 - compute the total acceleration vector of the orbiter to match the initial state at the time T_LAST_FILT, for use in the covariance propagation subfunction.

$$\underline{\text{TOT\_ACC}} = \underline{\text{ACCEL\_PERT\_ONORBIT}}\ (\text{GM\_DEG, GM\_ORD}, 1, 1, 0, \underline{\text{R}}\text{\_FILT}, \underline{\text{V}}\text{\_FILT}, \text{T\_LAST\_FILT}) - \text{EARTH\_MU}\ \underline{\text{R}}\text{\_FILT} / |\underline{\text{R}}\text{\_FILT}|^3$$

1.1.8 - initialize the 6 x 6 orbiter position/velocity portion of the covariance matrix to values transferred across the memory transition from ops 3 or ops 8.

$$E_{I,J} = \text{E\_INIT}_{I,J}$$

for I = 1 to 6, J = 1 to 6

1.1.9 - set a flag indicating to subfunctions of the orbit navigation principal function, that rendezvous navigation is de-activated.

REND_NAV_FLAG = OFF

1.1.10 - and, set a second flag indicating that IMU data is not to be used for navigation and user state propagation

USE_IMU_DATA = OFF

1.1.11 - signal that the proper initialization has been accomplished to allow the onorbit/rendezvous user parameter processing sequencer principal function to be scheduled

SIGNAL: OPS_2 OR_8_INITIALIZE COMPLETE

1.1.12 - set a flag which indicates use of the coasting flight state propagation algorithm

PWRD_FLT_NAV = OFF

After completion of initialization, the capability shall be provided for sequencing the onorbit navigation principal function at the designated repetition rate (DT_ONORBIT_NAV) for coasting flight.

If the onorbit coast navigation phase is begun by entry into MM 201 from ops-1 or ops-0 (via checkpoint initialization), events 60 or 81 respectively, the onorbit/rendezvous navigation sequencer principal function shall provide the capability to initialize the orbiter state vector, covariance matrix, and other required navigation parameters on the basis of prestored data and ops-1 or checkpoint data obtained from protected computer program memory load reconfiguration. The following sequence shall be performed:

1.2.1 - if re-initialization is to occur based on checkpoint data (event 81), perform the following functions

a. snap current IMU accumulated velocity and associated time tag

(see section 4.2.1.1 for detailed requirements of this SNAP function)

b. envoke the onorbit precision state prediction principal function to bring the checkpoint state vector (R_CHECK_PT, V_CHECK_PT) from stored time (T_CHECK_PT) to current time (T_LAST_FILT_INIT)

CALL: ONORBIT_PREDICT

INLIST: GM_DEG, GM_ORD, 1,1,1, PREC_STEP,
R_CHECK_PT, V_CHECK_PT, T_CHECK_PT,
T_LAST_FILT_INIT

OUTLIST: R_FILT_INIT, V_FILT_INIT

(see section 4.5.2 for detailed requirements of the onorbit prediction principal function)

Once this step (1.2.1) is completed, or if event 60 had occurred, instead of 81, proceed to the next step (1.2.2).

1.2.2 - (perform steps 1.1.1 through 1.1.7, above)

1.2.3 - initialize the 6 x 6 dimensional orbiter position/velocity covariance matrix to pre-stored UVW standard deviations and correlation coefficients.

CALL: ONORBIT_COVINIT_UVW

INLIST: SIG_UVW_OPS_2, COV_COR_OPS_2,
R_FILT, V_FILT

OUTLIST: $E_{1 \text{ to } 6,\ 1 \text{ to } 6}$

4.1.1-17

detailed requirements for the above subfunction are described in section 4.2.9.

1.2.4 - (perform steps 1.1.9 through 1.1.12, above)

After completion of initialization, the capability shall be provided for sequencing the onorbit navigation principal function at the designated repetition rate (DT_ONORBIT_NAV) for coasting flight.

If the onorbit coast navigation phase is begun by entry into MM 201 from MM 202 (event 73), the onorbit/rendezvous navigation sequencer principal function shall provide the capability to cancel operation of the onorbit navigation principal function. Initialization shall be performed as follows:

1.3.1 - set a flag indicating the non-use of IMU data for navigation and user propagation

USE_IMU_DATA = OFF

1.3.2 - set a flag indicating the usage of a coasting flight integration algorithm for navigation state propagation

PWRD_FLT_NAV = OFF

After completion of this initialization, the capability shall be provided for sequencing the onorbit navigation principal function at the designated repetition rate (DT_ONORBIT_NAV) for coasting flight.

If the onorbit coast navigation phase is begun by entry into MM 201 from MM 211 or MM 213 (events 61 or 61A, respectively), the onorbit/rendezvous navigation sequencer principal function shall provide the capability to cancel operation of the rendezvous navigation principal function. The following initializations shall then be performed:

1.4.1 - set a flag indicating the activation of onorbit navigation (and de-activation of rendezvous navigation).

REND_NAV_FLAG = OFF

1.4.2. - store the current target state vector time tag (for potential use when re-initialize rendezvous navigation at a later time)

T_TV = T_CURRENT_FILT

1.4.3 - (perform steps 1.3.1 and 1.3.2, above)

After completion of this initialization, the capability shall be provided for sequencing the onorbit navigation principal function at the designated repetition rate (DT_ONORBIT_NAV) for coasting flight.

If the onorbit coast navigation phase is begun by entry into GN&C ops-8 from ops-1 (event 50) the onorbit/rendezvous navigation sequencer principal function shall provide the capability to initialize the orbiter state vector, covariance matrix, and other required navigation parameters on the basis of prestored data and ops-1 data obtained from protected

computer program memory load reconfiguration. The following initialization sequence shall be performed:

1.5.1 - (perform steps 1.1.1 through 1.1.7, above)

1.5.2 - initialize the 6 x 6 dimensional orbiter covariance matrix to prestored UVW standard deviations and correlation coefficients:

CALL: ONORBIT_COVINIT_UVW

INLIST: SIG_UVW_OPS_2, COV_COR_OPS_2,
R_FILT, V_FILT

OUTLIST: $E_{1 \text{ to } 6,\ 1 \text{ to } 6}$

(see section 4.2.9 for detailed requirements of this common subfunction).

1.5.3 - set a flag to indicate the non-usage of IMU data for navigation and user state propagation

USE_IMU_DATA = OFF

1.5.4 - indicate completion of initialization of parameters for use by the onorbit/rendezvous user parameter processing sequencer principal function

SIGNAL: OPS_2_OR_8_INITIALIZE COMPLETE

1.5.5 - set a flag indicating the activation of onorbit navigation (and de-activation of rendezvous navigation)

REND_NAV_FLAG = OFF

1.5.6 - set a flag indicating the use of the coasting flight integration scheme for state propagation

PWRD_FLT_NAV = OFF

After completion of this initialization, the capability shall be provided for sequencing the onorbit navigation principal function at the designated repetition rate (DT_ONORBIT_NAV) for coasting flight.

If the onorbit coast navigation phase is begun by entry into GN&C ops-8 from ops-2 (event 60B), the onorbit/rendezvous navigation sequencer principal function shall provide the capability to initialize the orbiter state vector, covariance matrix, and other required navigation parameters on the basis of prestored data and ops-2 data obtained from protected computer locations unaffected by the computer program memory load reconfiguration. The following initialization sequence shall be performed:

1.6.1 - (perform steps 1.1.1 through 1.1.7, above)

1.6.2 - initialize the 6 x 6 dimensional orbiter position/velocity covariance matrix to values transferred across the memory transition from ops-2 to ops-8

$$E_{I,J} = E\_INIT_{I,J}$$

for I = 1 to 6, J = 1 to 6

1.6.3 - (perform steps 1.5.3 through 1.5.6, above)

After completion of this initialization, the capability shall be provided for sequencing the onorbit navigation principal function at the designated repetition rate (DT_ONORBIT_NAV) for coasting flight.

2. Onorbit Powered Flight Navigation Phase - This phase shall use the onorbit navigation principal function, and shall be active during MM 202 only, and shall begin upon the occurrence of event 60 (OMS ignition minus Y seconds). The onorbit/rendezvous navigation sequencer principal function will first cancel operation of the onorbit navigation principal function (the REND_NAV_FLAG will be in the OFF configuration during this navigation phase). The only initialization required is to set a flag indicating the use of the powered flight integration scheme for state propagation

PWRD_FLT_NAV = ON

After completion of this initialization, the capability shall be provided for sequencing the onorbit navigation principal function at the designated repetition rate (DT_ONORBIT_PWRD_FLT) for onorbit powered flight.

3. Rendezvous Coast Navigation Phase - This phase shall use the rendezvous navigation principal function and shall be active during operation of major modes 211, 212 and 213. The rendezvous coast navigation phase shall begin in one of the following ways:

. Entry into MM 211 from ops-1 (event 74),

. Entry into MM 211 from MM 201 (event 64), or

. Entry into MM 211 from MM 212 (event 78).

If the rendezvous coast navigation phase is begun by entry into MM 211 from ops-1 (event 74), the onorbit/rendezvous navigation sequencer principal function shall provide the capability to initialize the orbiter and target state vectors, covariance matrix, and other required navigation parameters on the basis of prestored data and ops-1 data obtained from protected computer locations unaffected by the computer program memory load reconfiguration. The following initialization sequence shall be performed:

3.1.1 - initialize orbiter state vector, covariance matrix and other parameters as indicated by steps 1.1.1 through 1.1.7.

3.1.2 - initialize the 6 x 6 dimensional orbiter position/velocity covariance matrix to prestored UVW standard deviations and correlation coefficients

CALL: ONORBIT_COVINIT_UVW

INLIST: $\underline{SIG}$_UVW_OPS_2, $\underline{COV}$_COR_OPS_2, $\underline{R}$_FILT, $\underline{V}$_FILT

OUTLIST: $E_{1 \text{ to } 6,\ 1 \text{ to } 6}$

(see section 4.2.9 for detailed requirements)

3.1.3 - set a flag indicating that a rendezvous navigation phase has been initialized

REND_NAV_FLAG = ON

3.1.4 - test a flag (TARG_VEC_AVAIL) indicating the presence (ON) or absence (OFF) of a stored target position/velocity state vector from which to initialize the rendezvous coast navigation phase.

3.1.5 - if the TARG_VEC_AVAIL flag is ON, then initialize target state and covariance matrix according to the following sequence:

a. predict the stored target position vector (R_TV) and velocity vector (V_TV) from time T_TV to the current time (T_CURRENT_FILT) by use of the onorbit precision state prediction principal function

CALL: ONORBIT_PREDICT

INLIST: GM_DEG, GM_ORD, DRAG_MODE_NAV,
0,3,PREC_STEP, R_TV, V_TV, T_TV,
T_CURRENT_FILT

OUTLIST: R_TV, V_TV

(see section 4.5.2 for detailed requirements)

b. initialize the 6 x 6 dimensional target position/velocity covariance matrix to prestored standard deviations and correlation coefficients

CALL: ONORBIT_COVINIT_UVW

INLIST: SIG_TV_UVW, COV_COR_TV,
R_TV, V_TV

OUTLIST: $E_{10 \text{ to } 15,\ 10 \text{ to } 15}$

(see section 4.2.9 for detailed requirements of this common subfunction).

c. compute the current total acceleration vector of the target vehicle for use by the covariance propagation subfunction.

$$\underline{G}\_TV = ACCEL\_PERT\_ONORBIT\ (GM\_DEG,\ GM\_ORD,\ DRAG\_MODE\_NAV,\ 0,3,\ PREC\_STEP,\ \underline{R}\_TV,\ \underline{V}\_TV,\ T\_CURRENT\_FILT) - EARTH\_MU\ \underline{R}\_TV/|\underline{R}\_TV|^{3}$$

(see section 4.2.1.2 for detailed requirements pertaining to usage of the acceleration models)

3.1.6 - if the TARG_VEC_AVAIL flag is OFF, initialize target state vector (R_TV, V_TV), total acceleration vector (G_TV), and time tag (T_TV) to orbiter values

$\underline{R}\_TV = \underline{R}\_FILT$

$\underline{V}\_TV = \underline{V}\_FILT$

$G\_TV = \underline{T}OT\_ACC$

$T\_TV = T\_LAST\_FILT$

also set target position/velocity covariance matrix equal to orbiter matrix.

$$E_{10\ to\ 15,\ 10\ to\ 15} = E_{1\ to\ 6,\ 1\ to\ 6}$$

3.1.7 - regardless of the TARG_VEC_AVAIL flag setting, set the following user parameter propagation subfunction target state vectors for use in initialiaation of that subfunction by the onorbit/rendezvous user parameter processing sequencer principal function

R_TV_RESET = R_TV

V_TV_RESET = V_TV

3.1.8 - set a flag indicating non-usage of IMU data by the navigation and user parameter state propagation subfunctions.

USE_IMU_DATA = OFF

3.1.9 - indicate the completion of that portion of initialization required for the onorbit/rendezvous user parameter processing sequencer principal function.

SIGNAL: OPS_2_OR_8_INITIALIZE COMPLETE

3.1.10 - set a flag indicating that the coasting flight (precision)propagation scheme shall be used for orbiter state advancement

PWRD_FLT_NAV = OFF

3.1.11 - set a flag indicating that external measurement data processing is to be permitted in this navigation phase

USE_MEAS_DATA = ON

3.1.12 - set a flag indicating that the target state has been initialized

TARG_VEC_AVAIL = ON

3.1.13 - zero counters related to the measurement processing statistics subfunction (see Section 4.3.2.8)

N_ACCEPT = 0

N_REJECT = 0

SEQ_ACCEPT = 0

SEQ_REJECT = 0

After completion of this initialization, the capability shall be provided for sequencing the rendezvous navigation principal function at the designated repetition rate (DT_REND_NAV) for the rendezvous coast navigation phase.

If the rendezvous coast navigation phase is begun by entry into MM 211 from MM 201 (event 64), the onorbit/rendezvous sequencer principal function shall provide the capability to initialize target vehicle state vector from one of the following options:

. based on pre-mission values,

. based on ground uplink data,

. based on last value in previous rendezvous navigation phase (predicted to current time), or

. set to orbiter state value at current time.

The onorbit/rendezvous navigation sequencer principal function shall also be capable of initializing the target position/velocity covariance matrix based on pre-stored UVW data. The first action of the sequencer upon occurence of event 64 is to cancel operation of the onorbit navigation principal function. The following initialization sequence shall then be performed:

3.2.1 - initialize target state & covariance matrix (perform steps 3.1.3 through 3.1.7, above)

3.2.2 - set a flag indicating the non-usage of IMU data in the navigation and user state propagation subfunctions for orbiter)

USE_IMU_DATA = OFF

3.2.3 - (perform steps 3.1.10 through 3.1.13, above)

After completion of this initialization, the capability shall be provided for sequencing the rendezvous navigation principal function at the designated repetition rate (DT_REND_NAV) for the rendezvous coast navigation phase.

If the rendezvous coast navigation phase is begun by entry into MM 211 from MM 212 (event 78), the onorbit/rendezvous navigation sequencer principal function shall provide the capability to cancel operation of the rendezvous navigation principal function. The following initialization is required, once this cancellation has been accomplished:

3.3.1 - set a flag indicating the non-usage of IMU data in the navigation and user state propagation subfunctions (for orbiter).

USE_IMU_DATA = OFF

3.3.1 - (perform steps 3.1.10 through 3.1.13, above)

After completion of this initialization, the capability shall be provided for sequencing the rendezvous navigation principal function at the designated repetition rate (DT_REND_NAV) for the rendezvous coast navigation phase.

4. Rendezvous Powered Flight Navigation Phase- This phase shall use the rendezvous navigation principal function, and shall be active during MM 212, only, and shall begin upon the occurrence of event $\overline{68}$ (OMS ignition minus y seconds).

4.1.1-28

The onorbit/rendezvous navigation sequencer principal function will first cancel operation of the rendezvous navigation principal function (the REND_NAV_FLAG will be in the ON configuration during this navigation phase). The only initialization required is to set a flag indicating the use of the powered flight integration scheme for orbiter state propagation

PWRD_FLT_NAV = ON

After completion of this initialization, the capability shall be provided for sequencing the rendezvous navigation principal function at the designated repetition rate (DT_REND_PWRD_FLT) for the rendezvous powered flight navigation phase.

5. TPF Stationkeeping Navigation Phase - This phase shall use the rendezvous navigation principal function and shall be active during operation of major mode 213. The TPF stationkeeping navigation phase shall begin in one of the following ways:

- Entry to MM 213 from MM 201 (event 66),
- Entry into MM 213 from MM 212 (event 79), or
- Entry into MM 213 from MM 211 (event 82).

If the TPF stationkeeping navigation phase is begun by entry into MM 213 from MM 201 (event 66), the onorbit/rendezvous navigation sequencer principal function shall provide the capability to, first, cancel operation of the onorbit navigation principal function. The following initialization is

required once this cancellation has been accomplished:

5.1.1 - initialize target state and covariance matrix (perform steps 3.1.3 through 3.1.7, above)

5.1.2 - set a flag indicating the usage of the powered flight navigation state propagation algorithm for orbiter position/velocity advancement.

PWRD_FLT_NAV = ON

5.1.3 - set a flag indicating that rendezvous external measurement data incorporation may occur in this navigation phase

USE_MEAS_DATA = ON

5.1.4 - set a flag indicating that a target state vector has been initialized

TARG_VEC_AVAIL = ON

After completion of the above initialization, the capability shall be provided for sequencing the rendezvous navigation principal function at the designated repetition rate (DT_REND_TPF_NAV) for the TPF stationkeeping navigation phase.

If the TPF stationkeeping navigation phase is begun by entry into MM 213 from MM 213 (event 79), or by entry into MM 213 from MM 211 (event 82), the onorbit/rendezvous navigation sequencer principal function shall provide the capability to, first, cancel operation of the rendezvous navigation principal function. The following initialization shall then be

performed:

5.2.1 - set a flag indicating the usage of the powered flight navigation state propagation algorithm for orbiter position/velocity advancement

PWRD_FLT_NAV = ON

5.2.2 - set a flag indicating that rendezvous external measurements data incorporation may occur in this navigation phase

USE_MEAS_DATA = ON

5.2.3 - set a flag indicating that a target state vector is available for future initialization if re-enter a rendezvous related navigation phase

TARG_VEC_AVAIL = ON

After completion of the above initialization, the capability shall be provided for sequencing the rendezvous navigation principal function at the designated repetition rate (DT_REND_TPF_NAV) for the TPF stationkeeping navigation phase.

6. Non-Phase-Related Requirements - In addition to the above requirements, which have been described on the basis of entrance into one of the five orbital navigation phases, there are three other categories of requirements to which the onorbit/rendezvous navigation sequencer principal function shall comply:

- inhibiting of external measurement data incorporation prior to an OMS burn,

. data to be saved in preparation for computer memory load transitions, and

. navigation data required to be saved via CHECKPOINT specialist function (and requirements as to the storage frequency of such data sets).

6.1 Inhibiting of External Data Processing: -

The onorbit/rendezvous navigation sequencer principal function shall provide the capability of setting a flag

USE_MEAS_DATA = OFF

which will be tested by the rendezvous navigation principal function for the purpose of inhibiting processing of external measurement data just prior to an OMS burn (ignition minus X seconds, event TBD). This flag setting shall occur independently of the entrance into the onorbit or rendezvous powered flight navigation phases, which occur at OMS ignition minus Y seconds (event 68).

6.2 - Memory Transition Data Save: -

The onorbit/rendezvous navigation sequencer principal function shall provide the capability to save off (in protected memory locations) certain data sets for transmission accross a memory transition, from one operational sequence to another. The following three cases require such storage:

. transition from MM 201 (ops-2) to GN&C ops-8 (event 60B),

. transition from MM 201 (ops-2) to ops-3 (event E1), or

. transition from GN&C ops-8 to MM 201 (ops-2), event 60A.

Prior to termination of ops-2 or ops-8, for the above three cases, the following variables shall be saved off

$\underline{R}$_FILT_INIT = $\underline{R}$_FILT

$\underline{V}$_FILT_INIT = $\underline{V}$_FILT

$\underline{V}$_LAST_FILT_INIT = $\underline{V}$_LAST_FILT

$\underline{E}\_INIT_{I,J} = E_{I,J}$ for I = 1 to 6, J = 1 to 6

Although the variable names with the "_INIT" have been designated as unique variables, this may not be required if the same physical core location can be used for $\underline{R}$ FILT (for example) in each memory load. The "_INIT" notation has been used for visibility purposes, only.

6.3 - CHECKPOINT Data: -

Although the VU (Vehcile Utilities) FSSR shall specify detailed requirements for storage and retrieval of GN&C data in association with the CHECKPOINT specialist function, the onorbit/rendezvous navigation sequencer principal function shall be capable of initializing the onorbit navigation principal function from such data sets. A detailed list of all data required to be stored for purposes of re-initializing the navigation system is provided in section 4.8 of this FSSR. The following additional requirements are to be provided:

- CHECKPOINT data sets shall be stored (via the CHECKPOINT specialist function) periodically, at a TBD rate
- CHECKPOINT data sets shall also be stored as soon as possible after each burn, and as soon as possible after each ground-update (of orbiter state vector)

4.1.1-33

. navigation reinitialization from a CHECKPOINT data set shall always be functionally similar to entrance into ops 2 from ops 1 (with the exception of having to predict CHECKPOINT orbiter position/velocity vectors to current time)

B. Interface requirements. Input and output parameters are given in tables 4.1.1-4 and 4.1.1-5, respectively.

C. Processing requirements. None.

TABLE 4.1.1-4 - (Continued) ONORBIT/RENDEZVOUS NAVIGATION SEQUENCER INPUT LIST

DESCRIPTION	SYMBOL	INPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	SAMPLE RATE
flag indicating (ON) the availability of a target vehicle state vector and time tag for reinitialization purposes	TARG_VEC_AVAIL	*	D	_	ON/OFF	_	As rqd
target position vector (M50)	R_TV	*	V	DP	_	ft	As rqd
target velocity vector (M50)	V_TV	*	V	DP	_	ft/sec	As rqd
time tag of target vehicle state vector	T_TV	*	F	DP	_	sec	As rqd

* ONORBIT/RENDEZVOUS NAVIGATION SEQUENCER PRINCIPAL FUNCTION INPUT LIST

TABLE 4.1.1-4 ONORBIT/RENDEZVOUS NAVIGATION SEQUENCER INPUT LIST

DESCRIPTION	SYMBOL	INPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	SAMPLE RATE
orbiter position vector (M50) saved across memory transition	R_FILT_INIT	*	V	DP	-	ft	As rqd
orbiter velocity vector (M50) saved across memory transition	V_FILT_INIT	*	V	DP	-	ft/sec	As rqd
total accumulated IMU sensed velocity saved across memory transition (M50)	V_LAST_FILT_INIT	*	V	DP	-	ft/sec	As rqd
time tag of navigation initialization data saved across memory transition	T_LAST_FILT_INIT	*	F	DP	-	sec	As rqd
position/velocity (6 x 6) orbiter covariance matrix (M50) saved across memory transition	E_INIT	*	M	DP	-	vary	As rqd

* Onorbit/rendezvous navigation sequencer principal function input list

TABLE 4.1.1-4 - (Continued) ONORBIT/RENDEZVOUS NAVIGATION SEQUENCER INPUT LIST

DESCRIPTION	SYMBOL	INPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	SAMPLE RATE
time tag of current filter state vector	T_CURRENT_FILT	*	F	DP	_	sec	As rqd
orbiter position vector (M50) saved via CHECKPOINT specialist function	R_CHECK_PT	*	V	DP	_	ft	As rqd
orbiter velocity vector (M50) saved via CHECK-POINT specialist function	V_CHECK_PT	*	V	DP	_	ft/sec	As rqd
time tag of orbiter state vector saved via CHECKPOINT specialist function	T_CHECK_PT	*	F	DP	_	sec	As rqd
sequencing time interval for onorbit navigation during onorbit coast phase	DT_ONORBIT_NAV	**	F	DP	_	sec	As rqd
sequencing time interval for rendezvous navigation during rendezvous coast phase	DT_REND_NAV	**	F	DP	_	sec	As rqd

* ONORBIT/RENDEZVOUS NAVIGATION SEQUENCER PRINCIPAL FUNCTION INPUT LIST
** PRE-MISSION LOAD

TABLE 4.1.1-4 - (Continued) ONORBIT/RENDEZVOUS NAVIGATION SEQUENCER INPUT LIST

DESCRIPTION	SYMBOL	INPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	SAMPLE RATE
sequencing time interval for onorbit navigation during onorbit powered flight phase,	DT_ONORBIT_PWRD_FLT	**	F	DP	—	sec	As rad
sequencing time interval for rendezvous navigation during rendezvous powered flight phase	DT_REND_PWRD_FLT	**	F	DP	—	sec	As rqd

** PRE-MISSION LOAD

TABLE 4.1.1-4 - (Continued) ONORBIT/RENDEZVOUS NAVIGATION SEQUENCER INPUT LIST

DESCRIPTION	SYMBOL	INPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	SAMPLE RATE
sequencing time interval for rendezvous nagation during TPF stationkeeping phase	DT_REND_TPF_NAV	**	F	DP	—	sec	As rqd
vector (6 x 1) standard deviations (UVW) for orbiter position/velocity covariance initialization	SIG_UVW_OPS_2	**	V	DP	—	vary	As rqd
vector (7 x 1) correlation coefficients associated with the UVW standard deviations SIG_UVW_OPS_2, used for orbiter position/velocity covariance initialization	COV_COR_OPS_2	**	V	DP	—	—	As rqd
vector (6 x 1) of standard deviations (UVW) for target vehicle position/velocity covariance initialization	SIG_TV_UVW	**	V	DP	—	vary	As rqd

** PRE-MISSION LOAD

TABLE 4.1.1-4 - (Continued) ONORBIT/RENDEZVOUS NAVIGATION SEQUENCER INPUT LIST

DESCRIPTION	SYMBOL	INPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	SAMPLE RATE
vector (7 x 1) correlation coefficients associated with the UVW standard deviations SIG_UVW_OPS_2, used for orbiter position/velocity covariance initialization	COV_COR_OPS_2	**	V	DP	_	_	As rqd
vector (6 x 1) of standard deviations (UVW) for target vehicle position/velocity covariance initialization	SIG_TV_UVW	**	V	DP	_	vary	As rqd
vector (7 x 1) of correlation coefficients associated with the UVW standard deviations SIG_TV_UVW, used for target position/velocity covariance initialization	COV_COR_TV	**	V	DP	_	_	As rqd
flag indicating degree of gravitational potential model	GM_DEG	**	I	S	1-8	_	As rqd

** PRE-MISSION LOAD

TABLE 4.1.1-4 - (Continued) ONORBIT/RENDEZVOUS NAVIGATION SEQUENCER INPUT LIST

DESCRIPTION	SYMBOL	INPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	SAMPLE RATE
flag indicating order of gravitational potential model	GM_ORD	**	I	S	0-8	—	As rqd
integration step-size for precision state prediction	PREC_STEP	**	F	DP	—	sec	As rqd
Earth gravitational constant	EARTH_MU	**	F	DP	—	ft^3/sec	As rqd
flag which activates (1) or de-activates (0) the drag acceleration model	DRAG_MODE_NAV	**	I	S	0-1	—	As rqd
flag which activates (1) or de-activates (0) the venting & RCS uncoupled thrusting models	VENT_MODE_NAV	**	I	S	0-1	—	As rqd
vector (3 x 1) of unmodeled acceleration bias error variances (body coord. system)	COV_ACCEL_BODY_INIT	**	V	DP	—	ft^2/sec	As rqd

** PRE-MISSION LOAD

TABLE 4.1.1-4 - (Continued) ONORBIT/RENDEZVOUS NAVIGATION SEQUENCER INPUT LIST

DESCRIPTION	SYMBOL	INPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	SAMPLE RATE
angle to earth's atmospheric bulge (Russian density model)	MAX_DENS_ANGLE	**	F	DP	—	rad	As rqd
angle to reference point in atmosphere (Russian density model)	MIN_DENS_ANGLE	**	F	DP	—	rad	As rqd
(see section 4.8.1-Load Requirements)	(acceleration model and predictor constants)	**	—	—	—	—	As rqd

** PRE-MISSION LOAD

TABLE 4.1.1-5 ONORBIT/RENDEZVOUS NAVIGATION SEQUENCER OUTPUT LIST

DESCRIPTION	SYMBOL	OUTPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	COMPUTATION RATE
signal to MSC indicating (COMPLETE) initialization of user parameter state propagation quantities is complete	OPS_2_OR_8 INITIALIZE COMPLETE	*	Signal	_	_	_	As rqd
orbiter position vector (M50)	R_FILT	*	V	DP	_	ft	As rqd
orbiter velocity vector (M50)	V_FILT	*	V	DP	_	ft/sec	As rqd
total accumulated IMU sensed velocity (M50)	V_LAST_FILT	*	V	DP	_	ft/sec^2	As rqd
time tag of V_LAST_FILT, & of filter state at last navigation cycle	T_LAST_FILT	*	S	DP	_	sec	As rqd
filter covariance matrix max. dimension is (19 x 19)	E	*	M	DP	_	vary	As rqd

* ONORBIT/RENDEZVOUS NAVIGATION SEQUENCER PRINCIPAL FUNCTION OUTPUT LIST

TABLE 4.1.1-5 - (Continued) ONORBIT/RENDEZVOUS NAVIGATION SEQUENCER OUTPUT LIST

DESCRIPTION	SYMBOL	OUTPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	COMPUTATION RATE
flag indicating whether rendezvous navigation active (ON) or onorbit navigation active (OFF)	REND_NAV_FLAG	*	D	_	ON/OFF	_	As rqd
flag indicating use of powered flight propagater (ON) or coasting flight propagator (OFF)	PWRD_FLT_NAV	*	D	_	ON/OFF	_	As rqd
square root of earth gravitational constant (EARTH_MU)	SQR_EMU	*	F	DP	_	$\frac{sec^3}{ft^2}$	As rqd
cosine of MIN_ DENS_ ANGLE (Russian Density model)	C_MN_AN	*	F	DP	_	_	As rqd
sine of MIN_ DENS_ANGLE (Russian density model)	S_MN_AN	*	F	DP	_	_	As rqd
cosine of MAX_DENS_ANGLE (Russian density model)	C_MX_AN	*	F	DP	_	_	As rqd

* ONORBIT/RENDEZVOUS NAVIGATION SEQUENCER PRINCIPAL FUNCTION OUTPUT LIST

TABLE 4.1.1-5 - (Continued) ONORBIT/RENDEZVOUS NAVIGATION SEQUENCER OUTPUT LIST

DESCRIPTION	SYMBOL	OUTPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	COMPUTATION RATE
sine of MAX_DENS_ANGLE (Russian density model)	S_MX_AN	*	F	DP	_	_	As rqd
vector of total orbiter acceleration (M50)	TOT_ACC	*	V	DP	_	$\frac{ft}{sec^2}$	As rqd
vector (3 x 1) of un-modeled acceleration bias errors (body coord. system)	VENT_THRUST_BIAS	*	V	DP	_	$\frac{ft}{sec^2}$	As rqd
flag indicating the use (ON) or non-use (OFF) of external measurement data processing by filter during burn & burn targeting	USE_MEAS_DATA	*	D	_	ON/OFF	_	As rqd
target vehicle position vector (M50)	R_TV	*	V	DP	_	ft	As rqd
target vehicle velocity vector (M50)	V_TV	*	V	DP	_	ft/sec	As rqd

* ONORBIT/RENDEZVOUS NAVIGATION SEQUENCER PRINCIPAL FUNCTION OUTPUT LIST

TABLE 4.1.1-5 (Continued) ONORBIT/RENDEZVOUS NAVIGATION SEQUENCER OUTPUT LIST

DESCRIPTION	SYMBOL	OUTPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	COMPUTATION RATE
target vehicle total acceleration vector (M50)	G_TV	*	V	DP	_	$\frac{ft}{sec^2}$	As rqd
vector (4 x 1) of sensor mark-accept counters (one per sensor)	N_ACCEPT	*	V (INTEGER)	S	_	_	As rqd
vector (4 x 1) of sensor mark-reject counters (one per sensor)	N_REJECT	*	V (INTEGER)	S	_	_	As rqd
vector (4 x 1) of number of sequential marks of particular type rejected	SEQ_ACCEPT	*	V (INTEGER)	S	_	_	As rqd
vector (4 x 1) of number of sequential marks of particular type rejected	SEQ_REJECT	*	V (INTEGER)	S	_	_	As rqd
flag indicating usage (ON) or non-usage (OFF) of IMU data in orbiter navigation state propagation and user parameter state propagation	USE_IMU_DATA	*	D	_	ON/OFF	_	As rqd

* ONORBIT/RENDEZVOUS NAVIGATION SEQUENCER PRINCIPAL FUNCTION OUTPUT LIST

TABLE 4.1.1-5 (continued) ONORBIT/RENDEZVOUS NAVIGATION SEQUENCER OUTPUT LIST

DESCRIPTION	SYMBOL	OUTPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	COMPUTATION RATE
orbiter position vector (M50) used to reset user parameter state propagator	R_RESET	*	V	DP	_	ft	As rqd
orbiter velocity vector (M50) used to reset user parameter state propagator	V_RESET	*	V	DP	_	ft/sec	As rqd
total accumulated IMU sensed velocity (M50) used to reset parameter state propagator	V_IMU_RESET	*	V	DP	_	ft/sec	As reqd
time tag of parameters used to reset the user parameter state propagator at each navigation cycle completion	T_RESET	*	F	DP	_	sec	As rqd
flag indicating (ON) to the user parameter state propagator to reset to navigation data	FILT_UPDATE	*	V	DP	ON/OFF	_	As rqd
target vehicle position vector (M50) used to reset user parameter state propagator.	R_TV_RESET	*	D	_	ON/OFF	_	As rqd

* onorbit/rendezvous navigation sequencer principal function output list

TABLE 4.1.1-5 - (Continued) ONORBIT/RENDEZVOUS NAVIGATION SEQUENCER OUTPUT LIST

DESCRIPTION	SYMBOL	OUTPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	COMPUTATION RATE
target vehicle velocity vector (M50) used to reset user parameter state propagator	V_TV_RESET	*	V	DP	_	ft/sec	As rqd
orbiter position vector (M50) stored for transition to ops-3 or ops-8	R_FILT_INIT	*	V	DP	_	ft	As rqd
orbiter velocity vector (M50) stored for transition to ops-3 or ops-8	V_FILT_INIT	*	V	DP	_	ft/sec	As rqd
total accumulated IMU sensed velocity stored for transition to ops-3 or ops-8	V_LAST_FLT_ INIT	*	V	DP	_	ft/sec	As rqd
time tag of V_LAST_FILT_ INIT, stored for transition to ops-3 or ops-8	T_LAST_FILT_	*	F	DP	_	sec	As rqd
(6 x 6) dimensional filter covariance matrix of orbiter position/velocity, stored for transition to ops-3 or ops-8	E_INIT	*	M	DP	_	vary	As rqd

* ONORBIT/RENDEZVOUS NAVIGATION SEQUENCER PRINCIPAL FUNCTION OUTPUT LIST

D. Constraints. None.

E. Supplemental information. A suggested implementation of these requirements is illustrated in appendix B and appendix C.

ONORBIT_REND_NAV_SEQUENCER
OPS_2_OR_8_INITIALIZE
CHECKPOINT_INIT (CODE)
ONORBIT_COVINIT
ONORBIT_COVINIT_UVW
TARGET_NAV_INIT
DISPLAY_COUNT_INIT (CODE)

APPENDIX B

ONORBIT_PREDICT ~ APPENDIX C

4.1.2 On-Orbit/Rendezvous User Parameter Processing Sequencer

This principal function will provide a capability for initialization and control of the principal functions and subfunctions associated with the computations of user parameters during the on-orbit/rendezvous operational sequence. This sequencer will provide initialization and control of the on-orbit user parameter state propagation subfunction and those user parameter processing principal functions used for this operational sequence.

Events to be used as cues by the sequencer for performing the required initialization and sequencing are defined in the Level B GN&C CPDS. The particular events and a summary of the associated user parameter actions pertaining to this user parameter sequencer are given in Table 4.1.2-1.

A. Detailed Requirements. The on-orbit/rendezvous user parameter processing sequencer will be initiated upon the occurrence of any of the following events:

1. Major mode transition from 106 to 201
2. Transition from OPS-8 to major mode 201
3. Major mode transition from 301 to 201
4. Major mode transition from 106 to 211
5. Transition from OPS-00 to Major Mode 201

This sequencer shall be terminated upon the transition from ops-2 to ops-3, ops-8, or ops-00.

TABLE 4.1.2-1 - ONORBIT/RENDEZVOUS USER PARAMETER PROCESSING SEQUENCER EVENTS

EVENT NO.	EVENT NAME/DESCRIPTION	ACTION TAKEN BY SEQUENCER IN RESPONSE TO EVENT
60 or 74	Transition from OPS-1 to OPS-2	Initiate cyclic execution of onorbit user parameter state propagation and onorbit user parameter calculations at a repetition rate of 0.5 Hertz.
61	Transition from 301 to 201	Same as event 60 action.
84	Transition from OPS-00 to 201	Same as event 60 action.
60A	Transition from OPS-8 to 201	Initiate cyclic execution of onorbit user parameter calculations at a repetition rate of 0.5 Hertz.
73 or 80	Transition from 202 or 213 to 201	Same as event 60A action.
78	Transition from 212 to 211	Same as event 60A action.
76 or 82	Transition from 211 to 212 or 213	Cancel onorbit user parameter calculations module.
66 or 67	Transition from 201 to 202 or 213	Same as event 76 action.
69	Initiate guidance	Cancel onorbit user parameter state propagation. Reschedule cyclic processing of onorbit user parameter state propagation at a repetition rate of 0.5 Hertz.

The following paragraphs specify the detailed requirements that were summarized in table 4.1.2-1. These requirements specify, for each of the event cues to be utilized by the sequencer, the actions that the sequencer is to initiate.

Transition from OPS-1 to OPS-2 - Upon receipt of a signal

SIGNAL: OPS_2_INITIALIZATION COMPLETE

cyclic execution of the onorbit/rendezvous user parameter state propagator shall commence at a repetition rate of 0.5 Hertz. The signal is the cue that the necessary initialization of certain state parameters has been accomplished within the onorbit/rendezvous navigation sequencer (section 4.1.1). Cyclic processing of the onorbit user parameter calculations shall commence at a repetition rate of 0.5 Hertz.

Transition from OPS-3 to OPS-2 - Same as above.

Transition from OPS-00 to OPS-2 - Same as above.

Transition from OPS-8 to OPS-2 - Based upon this cue, cyclic processing of the onorbit user parameter calculations shall commence at a repetition rate of 0.5 Hertz.

Transition from 202 (maneuver execute) or 213 (TPF/stationkeeping) to 201 (orbit coast). - Same as above.

Transition from 212 (maneuver execute) to 211 (rendezvous navigation). - Same as above.

Transition from 201 to OPS-8. - Based upon this cue, cyclic processing of the onorbit user parameter calculations shall be cancelled.

Transition from 201 to 202 or 213. - Same as above.

Transition from 211 to 212 or 213. - Same as above.

Initiate guidance - Based upon this cue, the current scheduling of onorbit user parameter propagation is to be cancelled. Cyclic processing of onorbit user parameter processing is to be rescheduled at a repetition rate of 0.5 Hertz beginning with this event.

B. Interface requirements. The input list for this principal function is presented in Table 4.1.2-2.

C. Processing requirements. None.

D. Constraints. None

E. Supplemental information. The purpose of cancelling and rescheduling the onorbit user parameter propagator upon the initiate guidance signal is to get the execution of this module in "sync" with the execution of onorbit guidance which is to be initiated at this time. This cancelling and rescheduling is to be done "y" seconds prior to OMS ignition such that a subsequent user state update will occur, as nearly as possible, at the time of ignition.

A suggested implementation of the onorbit/rendezvous UPP sequencer in the form of detailed flow charts is shown in Appendix D, flow chart ONORBIT_REND_UPP_SEQ.

TABLE 4.1.2-2: ONORBIT/RENDEZVOUS USER PARAMETER PROCESSING PRINCIPAL FUNCTION INPUT LIST

LEVEL B MNEMONIC	DESCRIPTION	LEVEL C SYMBOL	INPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	SAMPLE RATE/sec
TBD	Transition to MM 201 from MM 106 event	Event 60	MSC	BIT		OFF_ON		25
	Transition to MM 201 from OPS-8 event	Event 60A	"	"		"		"
	Transition to MM 201 from MM 301 event	Event 61	"	"		"		"
	Transition to MM 213 from MM201 event	Event 66	"	"		"		"
	Transition to MM 202 from MM201 event	Event 67	"	"		"		"
	Guidance initiate event	Event 69	"	"		"		"
	Transition to MM201 from MM 202 event	Event 73	"	"		"		"
	Transition to MM 211 from MM106 event	Event 74	"	"		"		"
	Transition to MM 212 from MM 211 event	Event 76	"	"		"		"
	Transition to MM 211 from MM 212 event	Event 78	"	"		"		"
	Transition to MM 201 from MM 213 event	Event 80	"	"		"		"
	Transition to MM 213 from MM 211 event	Event 82	"	"		"		"
	Transition to MM 201 from OPS-00 event	Event 84	"	"		"		"
	Nav initialization Complete signal	OPS-2-Initialize Complete	Onorbit/ Rend signal NAV SEQ	SIGNAL		OFF_ON		"

4.2 SUBFUNCTIONS COMMON TO SEVERAL NAVIGATION FUNCTIONS

This section documents detailed requirements for subfunctions identified as being common to two or more navigation principal functions or their major subfunctions. The detailed requirements specified here will be referenced from the sections to which they are common and, when referenced, may be regarded as inserts to paragraph A - Detailed requirements - in these sections.

4.2.1 State Propagation

This subfunction will perform a number of tasks related to propagation of the orbiter and target state vectors. The task of reading (snapping) the IMU's is performed when the total accumulated sensed velocity is required to account for nongravitational accelerations during integration of the orbiter equations of motion. The appropriate modeled nongravitational accelerations (drag, venting, uncoupled thrusting) are computed in those circumstances in which IMU accumulated sensed velocity is not used. The orbiter equations of motion are integrated with the use of either a super-g algorithm designed primarily for powered-flight phases (i.e., those phases in which appreciable nongravitational accelerations are experienced), or a precision propagation algorithm designed specifically for coasting-flight phases. The target state vector is always propagated by use of the precision propagation algorithm. The task of propagation of sensor biases is performed in those navigation phases in which the corresponding sensor biases are being estimated by the filter.

4.2.1.1 IMU Data Snap

The IMU data snap task will provide the capability to obtain the orbiter IMU-sensed accumulated velocities, expressed in M50 coordinates, along with their associated GMT time tag. These data will be stored for use in the state propagation subfunction. Data from one good IMU are required as indicated in the following example:

```
SNAP IMU (V _CURRENT_FILT, T_CURRENT_FILT)
```

These data are obtained from the IMU RM.

The SNAP statement above implies the assignment of current values to the variable names shown in parentheses.

4.2.1.2 Acceleration Models

During orbital operations gravitational, drag, venting and uncoupled RCS thrusting acceleration models shall be available for state prediction or propagation. These models are to be used in the orbiter state propagation whenever the IMU-sensed accelerations are below a given threshold level. Propagation or prediction of the target vehicle's state shall use the gravitational and drag models.

The currently functioning propagator and a predictor may need different models at the same time. It is therefore necessary that the execution of the acceleration calculations be protected from interruption by other users.

For the computation of the accelerations due to the Earth's gravity, options shall be provided to include terms derived from various degree and order gravitational potential models. Input flags GMD and GMO shall be set by the user to specify, respectively, the degree and order of the gravitational potential model to be used. Similarly, an input flag, DM, shall be set by the user to indicate whether or not to model drag. Venting acceleration models shall be included to take into account those situations when venting of predictable magnitude, direction, and duration occurs. These models shall include the effects of any residual unbalance in the operation of the RCS thrusters; an input flag, VM, shall be set by the user to control operation of this task.

For the drag, venting, and uncoupled thrusting acceleration computations, it may be necessary to know the vehicle's attitude. Attitude affects the inertial direction of the acceleration due to venting and determines the cross-sectional area of the vehicle normal to the velocity vector relative to the ambient air for atmospheric drag. Another user defined flag, ATM, shall be used to control the options available in this attitude calculation, as described later in this section and in section 4.2.1.2.2.

The acceleration function shall be called by the user with values of GMD, GMO, DM, VM, ATM, $\underline{R}$, $\underline{V}$, and T, where $\underline{R}$ and $\underline{V}$ are the position and velocity vectors of the vehicle in an M50 coordinate system and T is the time tag associated with both of these vectors.

It shall then initialize various perturbing acceleration vectors,

$$\underline{G} = 0.$$

$$\underline{D} = 0.$$

$$\underline{RCS} = 0.$$

$$\underline{V}ENT = 0.$$

and obtain the transformation matrix from Earth-fixed to M50 coordinates in order to find the Earth-fixed position vector and the corresponding unit vector:

FIFTY = EARTH_FIXED_TO_M50_COORD(T)

$\underline{R}$ _EF = FIFTY^T $\underline{R}$

R_INV = 1./|$\underline{R}$|

UR = R_INV $\underline{R}$ _EF

There is no need to calculate the acceleration vector due to the Earth's gravitational attraction as a point mass; that task is performed directly by the predictors and the propagators. The on-orbit acceleration function determines only perturbing accelerations. This being the case, the disturbing acceleration $\underline{G}$ due to the Earth's non-spherical shape shall be calculated (see section 4.2.1.2.1).

The flags that control the use of drag, venting, and uncoupled RCS thrusting shall then be tested. If all are equal to zero, the vector $\underline{G}$ already contains all the accelerations required. If, however, one or more of these flags has a nonzero value, more calculations shall be needed.

If DM = 1, a drag acceleration vector $\underline{D}$ shall be determined. If VM = 1, a vector that accounts for venting and uncoupled thrusting accelerations, $\underline{\text{VENT}}$, must be obtained. In either one of the latter two cases, or if both flags have value 1, it may be necessary to determine the attitude matrix of the orbiter. There are circumstances, namely if the acceleration vector to be found is that of the target vehicle, or if the acceleration of the orbiter is required for a simplified state prediction used by guidance, in which the attitude matrix is not needed. The ATM flag shall be assigned values that specify whether or not the attitude matrix is required (see section 4.2.1.2.2). If the matrix is needed, the flag ATM shall

determine how it is to be calculated, depending on whether it is to be used for propagation or prediction purposes.

In brief, the values of the flag ATM are explained in the following table:

VEHICLE	FUNCTION	ATTITUDE MATRIX NEEDED	ATM FLAG SETTING
Orbiter	Propagation	Yes	0
	Prediction	Yes	1
	Simplified prediction (for guidance)	No	2
Target	All functions	No	3
Other target vehicles (if required)	All functions	No	>3

The attitude matrix calculation, if needed, shall occur prior to the calculation of the acceleration vectors due to drag or venting, and shall be done as follows.

For propagation (ATM = 0), the current selected body to M50 rotation matrix, available from the attitude processing principal function, is required:

$$M = \underline{M}\_M50BODY_K^T$$

For prediction (ATM = 1), data from the 2nd, 3rd, 4th, and 5th rows of a prestored attitude table (ATT_ARRAY) are to be used to construct the body to M50 rotation matrix. This rotation matrix shall be constructed in two steps. The first step shall use the Euler angles for the time period containing the given time T, obtained from the 3rd, 4th, and 5th rows of ATT_ARRAY, to construct the body to attitude mode matrix (also denoted M), valid at the beginning of the time period (i.e., T_INITIAL):

$$M = \left[\begin{array}{c:c:c} \begin{matrix} C3\ C1 \\ -S3\ C2\ S1 \end{matrix} & \begin{matrix} C3\ S1 \\ +S3\ C2\ C1 \end{matrix} & S3\ S2 \\ \hdashline \begin{matrix} -S3\ C1 \\ -C3\ C2\ S1 \end{matrix} & \begin{matrix} -S3\ S1 \\ +C3\ C2\ C1 \end{matrix} & C3\ S2 \\ \hdashline S2\ S1 & -S2\ C1 & C2 \end{array}\right]$$

where S1, S2, and S3 represent the sines of the Euler angles and C1, C2, and C3 represent the cosines of the Euler angles. This matrix will be a transformation from body to M50 if the attitude mode is an inertial hold, and from body to UVW if the attitude mode is a local-vertical, local-horizontal. Information about the various attitude holds, in the form of settings of a flag called ATT_FLAG, are stored in the second row of the ATT_ARRAY table. Attitude Profile Constants in section 4.8 contains the details of the table lookup.

The second step multiplies the body to attitude mode matrix by an attitude mode to M50 matrix, as appropriate. This attitude mode to M50 matrix and the required body to M50 rotation matrix

shall be determined as follows: If an inertial hold occurs during the time period (ATT_FLAG = 1), the matrix M is, in fact, the required body to M50 rotation matrix. If an inertial hold with rate occurs during the time period (ATT_FLAG = 2), the matrix M must only be updated from time T_INITIAL to time T since it already transforms from body to M50. This shall be accomplished with use of the theory of quaternions as follows:

1. Transform the unit vector in the eigen-axis direction (in body coordinates), obtained from the ATT_ARRAY, into M50:

$$\underline{EV} = M \begin{bmatrix} ATT\_ARRAY_{6,J-1} \\ ATT\_ARRAY_{7,J-1} \\ ATT\_ARRAY_{8,J-1} \end{bmatrix}.$$

2. Calculate the quaternion required to transform the matrix M from time T_INITIAL to time T:

$$SQ = COS(HANG)$$

$$\underline{VQ} = SIN(HANG)\ \underline{EV}$$

where

$$HANG = -.5\ ATT\_ARRAY_{9,J-1}\ (T-T\_INITIAL)$$

is the angular displacement in radians about the eigen-axis from T_INITIAL to T.

3. Calculate the required body to M50 rotation matrix:

$$M = [2.\ SQ^2 - 1.)\ ID\_MATRIX\_3X3 + 2.\ \underline{VQ}\ \underline{VQ}^T + 2.\ SQ\ M\_TEMP]\ M$$

where

$$M\_TEMP = \begin{bmatrix} 0. & -VQ_3 & VQ_2 \\ VQ_3 & 0. & -VQ_1 \\ -VQ_2 & VQ_1 & 0. \end{bmatrix}$$

is the skew-symmetric body axis rotation rate matrix. If a local-vertical, local-horizontal hold occurs during the time period (ATT_FLAG = 3 or 4) the matrix M, which transforms from body to UVW, must be multiplied by a UVW to M50 transformation matrix in order to produce the required rotation matrix:

$$M = M\ UVW\_TO\_M50(\underline{R}, \underline{V})$$

Another prerequisite to the calculation of either drag or venting accelerations is the knowledge of the right ascension and declination of the Sun. For venting accelerations, this is needed in the "inertial with rate" (or "barbecue") attitude mode (see section 4.2.1.2.3); for drag accelerations, it is used in the computation of the atmospheric density (see section 4.2.1.2.2). The solar coordinates shall be obtained by means of a call to the module SOLAR_EPHEM, described in section 4.5.3.1.

When the vectors $\underline{G}$, $\underline{D}$, and $\underline{VENT}$ have been obtained, the total modeled perturbing acceleration vector shall be found:

$$\underline{ACCEL\_PERT\_ONORBIT} = \underline{G} + \underline{D} + \underline{VENT}$$

The following paragraphs (4.2.1.2.1, 4.2.1.2.2, and 4.2.1.2.3) contain the detailed requirements for the calculation of these vectors - $\underline{G}$, $\underline{D}$, and $\underline{VENT}$. Interface and processing requirements, constraints, and supplementary information for all these tasks are

to be found in the descriptions of those principal functions that use them.

A suggested implementation in the form of a detailed flow chart may be found in appendix B. The various codes referenced in that flow chart are to be found also in appendix B:

ACCEL_EARTH_GRAV CODE

ACCEL_ONORBIT_DRAG CODE

ONORBIT_DENSITY CODE

ACCEL_ATTITUDE CODE

ACCEL_ONORBIT_VENT_AND_THRUST CODE

4.2.1.2.1 Gravity

The gravitational attraction due to the Earth's non-sphericity shall be modeled by using S. Pines' uniform formulation of the spherical harmonics development. This code shall be exercised only if the flag GMD is not equal to zero.

The following variables are to be set up to serve as starting values for the recursion relations used in the Pines formulation:

AUXILIARY = 0.

RO_ZERO = EARTH_RADIUS_GRAV R _INV

RO_N = RO_ZERO EARTH_MU R_INV^2

$A_{1,2}$ = 3. UR_3

$A_{2,2}$ = 3.

L = 1

A is a two-column array used for temporary storage of the Legendre polynomials and the derived Legendre functions (which are latitude-dependent terms), and RO_N is the distance-related term. AUXILIARY is an intermediate scalar variable.

The recursive calculations shall then proceed, using as many components of the one-column arrays ZETA_REAL and ZETA_IMAG as required to account for the effects of the tesseral harmonics. ZETA_REAL and ZETA_IMAG are the only terms that depend on the vehicle's longitude.

Do for I = 1 to GMO:

$$ZETA\_REAL_{I+1} = UR_1\ ZETA\_REAL_I - UR_2\ ZETA\_IMAG_I$$

$$ZETA\_IMAG_{I+1} = UR_1\ ZETA\_IMAG_I + UR_2\ ZETA\_IMAG_I$$

$ZETA\_REAL_1$ and $ZETA\_IMAG_1$, needed as starting values for this recursive calculation, are constants described in section 4.8.

The derived Legendre functions shall then be obtained by means of recursion formulas, multiplied by the appropriate combinations of tesseral harmonics (the Legendre polynomials shall be multiplied by the zonal harmonics coefficients), and stored as certain auxiliary variables F1, F2, F3, and F4.

Do for N = 2 to GMD the following steps (1 through 5):

1. $A_{N+1,1} = 0.$

   $A_{N+1,2} = (2.\ N + 1.)\ A_{N,2}$

   $A_{N,1} = A_{N,2}$

   $A_{N,2} = UR_3\ A_{N+1,2}$

   $K = 2$

2. Do for J = 2 to N:

   $A_{N-J+1,1} = A_{N-J+1,2}$

   $A_{N-J+1,2} = (UR_3\ A_{N-J+2,2} - A_{N-J+2,1})/K$

   $K = K + 1$

3. $F1 = 0.$

$F2 = 0.$

$F3 = -A_{1,1}\ ZONAL_N$

$F4 = -A_{1,2}\ ZONAL_N$

(These account for the zonal harmonics contributions.)

4. If the maximum order of tesserals wanted has not been attained (i.e., if $N \leq GMO$), do for N1 = 1 to N:

$F1 = F1 + N1\ A_{N1,1}\ (C_L\ ZETA\_REAL_{N1} + S_L\ ZETA\_IMAG_{N1})$

$F2 = F2 + N1\ A_{N1,1}\ (S_L\ ZETA\_REAL_{N1} - C_L\ ZETA\_IMAG_{N1})$

$DNM = C_L\ ZETA\_REAL_{N1+1} + S_L\ ZETA\_IMAG_{N1+1}$

$F3 = F3 + DNM\ A_{N1+1,1}$

$F4 = F4 + DNM\ A_{N1+1,2}$

$L = L + 1$

(These take into account the contributions of the tesseral and sectorial harmonics.)

5. RO_N = RO_N RO_ZERO

$G_1 = G_1 + RO\_N\ F1$

$G_2 = G_2 + RO\_N\ F2$

$G_3 = G_3 + RO\_N\ F3$

AUXILIARY = AUXILIARY + RO_N F4

(These equations multiply the sum of the zonal and tesseral effects by the appropriate distance-related factors, store the results as the components of the acceleration vector $\underline{G}$, and

prepare for final computation by obtaining the intermediate scalar variable AUXILIARY, which accounts for an additional effect proportional to the unit radius vector $\underline{UR}$.)

Once these calculations have been completed (N = GMD) and stored, the Earth-fixed acceleration vector shall be obtained and rotated to the M50 coordinate system.

$$\underline{G} = \underline{G} - \text{AUXILIARY } \underline{UR}$$

$$\underline{G} = \text{FIFTY } \underline{G}$$

This is the gravitational acceleration vector needed for the equations of motion of the shuttle. The values of GMD and of GMO may be set by the user independently. However, it is necessary that GMO $\leq$ GMD. A maximum value of 8 for GMD shall be used, which will make the array $\underline{Z}$ONAL have 8 components, the arrays $\underline{C}$ and $\underline{S}$ have 35 components each, $\underline{Z}$ETA_REAL and $\underline{Z}$ETA_IMAG have 9 each, and A have a maximum dimension of 9 by 2.

The terms shown in the Earth's gravity calculations as C_L and S_L are usually represented by $C_{n,m}$ and $S_{n,m}$, respectively, but were renumbered for single subscript utilization; the terms called $ZONAL_N$ correspond to $J_N = -C_{N,0}$.

The S. Pines formulation of the gravitational potential may be found, in condensed form, in the paper "Uniform Representation of the Gravitational Potential and its Derivatives," AIAA Journal,

vol. 11, no. 11, November 1973. In expanded form, and with an earlier draft of the computer program herein presented, it may be found in MDC Report No. W0013, NASA CR 147478, of 9 February 1976, "Pines' Nonsingular Gravitational Potential: Derivation, Description and Implementation".

4.2.1.2.2 Drag

The computation of drag accelerations will vary according to the values of an input indicator, designated here as DM.

The value $\underline{D}$ of this acceleration shall be set to zero when the acceleration function is called.

If DM = 0, the value of $\underline{D}$ shall not be changed.

If DM = 1, $\underline{D}$ shall be computed as

$$\underline{D} = -.5 \text{ CD AREA RHO } |\underline{V}\_R| \ \underline{V}\_R/\text{VEH\_MASS}$$

where CD is the vehicle's drag coefficient; VEH_MASS is its mass; $\underline{V}\_R = \underline{V}\_REL\ (\underline{V}, \underline{R})$, where $\underline{V}$ and $\underline{R}$ are, respectively, the velocity and position vectors in M50 coordinates; $\underline{V}$_REL is the function that computes the relative velocity of the vehicle with respect to the atmosphere (assuming no wind) -

$$\underline{V}\_REL(\underline{V},\underline{R}) = \underline{V} - \text{EARTH\_RATE } (\underline{\text{EARTH\_POLE}} \times \underline{R})$$

RHO is the density of the Earth's atmosphere; and AREA is a certain cross-sectional area of the vehicle, a prestored constant.

The calculations shall be performed in the following order: First, the altitude (needed for the computation of the atmospheric density, RHO) shall be obtained from the expression

$$\text{ALT} = \text{H\_ELLIPSOID}(\underline{R})$$

H_ELLIPSOID is the function that computes altitude above the reference ellipsoid.

K2, the factor in the mathematical model of the Earth's atmospheric density that has to do with the diurnal effects, shall then be obtained:

$$\text{SDEC} = \text{SDEC R\_INV } R_3$$

$$\text{CDEC2} = \text{CDEC1 R\_INV } R_2$$

$$\text{CDEC1} = \text{CDEC1 R\_INV } R_1$$

$$\text{SGAM1} = \text{SIN\_SOL\_RA C\_MX\_AN} + \text{COS\_SOL\_RA S\_MX\_AN}$$

$$\text{CGAM1} = \text{COS\_SOL\_RA C\_MX\_AN} - \text{SIN\_SOL\_RA S\_MX\_AN}$$

$$\text{SGAM2} = \text{SIN\_SOL\_RA C\_MN\_AN} + \text{COS\_SOL\_RA S\_MN\_AN}$$

$$\text{CGAM2} = \text{COS\_SOL\_RA C\_MN\_AN} - \text{SIN\_SOL\_RA S\_MN\_AN}$$

$$\text{COS\_PSI\_1} = \text{SDEC} + \text{CGAM1 CDEC1} + \text{SGAM1 CDEC2}$$

$$\text{COS\_PSI\_1} = \text{DIURN\_EFF\_5 } (1. + \text{COS\_PSI\_1})^{\text{CORR\_POWER\_1}}$$

$$\text{COS\_PSI\_2} = -\text{SDEC} + \text{CGAM2 CDEC1} + \text{SGAM2 CDEC2}$$

$$\text{COS\_PSI\_2} = \text{DIURN\_EFF\_6 } (1. + \text{COS\_PSI\_2})^{\text{CORR\_POWER\_2}}$$

$$\text{K2} = 1. + (\text{ALT} + \text{DIURN\_EFF\_1} + \text{DIURN\_EFF\_2 EXP}\{-[(\text{ALT} + \text{DIURN\_EFF\_3})/\text{DIURN\_EFF\_4}]^2\})\ (\text{COS\_PSI\_1} + \text{COS\_PSI\_2})$$

where SDEC and CDEC1, COS_SOL_RA and SIN_SOL_RA, respectively the sine and cosine of the solar declination and the cosine and sine of the solar right ascension, were previously obtained in the call to the solar ephemeris subfunction.

Two values of DOY_EFF needed for the K3 factor of the atmospheric density calculation, which has to do with the semiannual effect, shall be obtained from a table (see sec. 4.8), and K3 shall be

calculated with a linear interpolation between these values:

$$DAY\_OF\_YEAR = T/86400.$$

Set

$$I = 1.$$

Increment I in steps of 1 until

$$DAY\_OF\_YEAR \leq 10.I$$

Then, let

$$DAY\_ONE = 10.\ (I - 1)$$

Finally,

$$K3 = 1. + .1\ (ALT + ANNUAL\_EFF)[(DAY\_OF\_YEAR - DAY\_ONE)$$
$$(DOY\_EFF_{I+1} - DOY\_EFF_{I}) + 10.\ DOY\_EFF_{I}]$$

K1 and K4. the factors in the atmospheric density calculations that account for the solar radiation intensity in the 10.7-centimeter wavelength and for the geomagnetic disturbance, respectively, shall be computed:

$$K1 = 1. + (ALT + RAD\_EFF)\ SOL\_RAD\_EMIT\_CORRECT$$
$$K4 = 1. + (ALT + MAGN\_EFF)\ GEOMAG\_DISTURB\_CORRECT$$

The atmospheric density, RHO, shall then be obtained by the multiplication of these factors and a nighttime altitude/density profile:

$$RHO = K1\ K2\ K3\ K4\ NIGHT\_PROF\_1\ EXP\ [NIGHT\_PROF\_2\ (ALT + NIGHT\_PROF\_3)^{1/2}]$$

C·2

Besides the values of DOY_EFF, which are contained in a table, the values DIURN_EFF_1, DIURN_EFF_2, DIURN_EFF_3, DIURN_EFF_4, DIURN_EFF_6, CORR_POWER_1, CORR_POWER_2, ANNUAL_EFF, RAD_EFF, MAGN_EFF, NIGHT_PROF_1, NIGHT_PROF_2 and NIGHT_PROF_3 are constants contained in another table. There exist various tables of the two types, but only one of each is to reside in the memory load at a time. The tables may be found in section 4.8, separated into DOY_EFF tables and general density tables (for the other variables). The actual pair of tables to be loaded depends on the values of the solar radiation flux at the time of the mission.

Once the atmospheric density has been obtained, the velocity $\underline{V}\_R$, relative to the atmosphere but expressed in M50 coordinates, shall be found as explained above.

After the vector $\underline{V}\_R$ has been calculated, the attitude mode flag ATM shall be tested. This flag is utilized, in this case, to incorporate in the drag equation the appropriate values of the vehicle's mass, area, and drag coefficient. The first three values of ATM, 0, 1, and 2, refer to calculation of the orbiter's acceleration vector.

If ATM = 0 or 1, the current mass of the orbiter and its reference cross-sectional area shall be used in the equations, but its drag coefficient shall be calculated as described below. If ATM = 2, the

mass and area of the orbiter shall be the same, but the drag coefficient shall be set to a premission stored reference value. This setting is meant for utilization by guidance, for a fast, simplified state vector prediction. If ATM > 2, the acceleration vector to be computed is that of the target vehicle. The mass, area, and drag coefficient of this vehicle will therefore be used. For that purpose, these quantities shall be available as components of 3 vectors $\underline{R}EF\_MASS$, $\underline{R}EF\_CD$ and $\underline{R}EF\_AREA$, premission-stored, of which REF_MASS_1, REF_CD_1 and REF_AREA_1 pertain to the orbiter, and subsequent ones to as many target vehicles as needed for each particular mission.

The calculation of the orbiter's drag coefficient in the cases where ATM has values 0 or 1 shall be preceded by a table lookup to obtain the configuration of the orbiter vehicle. The configuration shall be specified by an integer variable J with values that indicate the external aspect of the shuttle: for instance, J = 1 for payload bay doors closed, J = 2 for the same doors open, J = 3 for manipulator arms extended, J = 4 for payload deployed, etc. The table lookup and the table itself are described in section 4.8.

The drag coefficient, in these cases, shall be obtained as a function of the square of the sine of the angle of attack (SA) and of the sine of the angle of sideslip (SB). If ATM = 0, which indicates the drag acceleration is to be used for orbiter state propagation (that is, for determination of the current state vector), these

sines can be obtained from currently available angles ALPHA and BETA from the attitude applications calculation principal function

$$SA = [SIN(ALPHA)]^2$$

$$SB = |SIN(BETA)|$$

If ATM = 1, the drag acceleration is to be utilized for orbiter state prediction (determination of the state vector at some time in the future or past) and the sines of the angles of attack and sideslip must be obtained from the velocity vector relative to the atmosphere but expressed in body coordinates:

$$\underline{V}\_REL\_BODY = M^T \underline{V}\_R$$

where M is the transformation matrix from body to M50 coordinates.

If the Z-component of this vector is practically zero (smaller in absolute value than some very small number EPS_VRB), the sine of the angle of attack shall be set to zero:

$$SA = 0$$

Otherwise, it shall be found from the formula

$$SA = |V\_REL\_BODY_3|^2/(V\_REL\_BODY_1^2 + V\_REL\_BODY_3^2)$$

In either case, the sine of the sideslip angle shall be computed with the expression

$$SB = |V\_REL\_BODY_2|/|\underline{V}\_R|$$

The sine of double the sideslip angle is also needed -

$$S2B = 2.\ SB\ SQRT(1. - SB^2)$$

and the drag coefficient for configuration J is given by

$$CD = (CDF_J + CDN_J \; SA^{EXP\_SHAPE\_FACTOR_J})(1. - SB) + CDS_J \; SB + CDA_J \; S2B \; SA$$

where CDF, CDN, CDA, CDS and EXP_SHAPE_FACTOR are constants described in section 4.8.

Finally, the drag acceleration shall be obtained from the expression

$$D = -.5 \; CD \; AREA \; RHO \; |\underline{V}\_R| \; \underline{V}\_R/VEH\_MASS$$

4.2.1.2.3 Venting and Uncoupled RCS Thrusting

The models for the acceleration due to venting and uncoupled thrusting shall be available for use in both orbiter state propagation and orbiter state prediction. It is assumed that the onboard software will have the capability to access from storage a time line of significant vent sources, as well as an attitude profile. This information shall be used to compute the vector $\underline{V}$ENT, the acceleration due to venting, which shall be used in the integration of the orbiter's equations of motion.

A flag (VM) shall be set to indicate whether or not venting acceleration shall be computed. A flag setting of VM = 0 shall indicate that the IMU-sensed accelerations are being used in state vector integration, and hence the venting acceleration vector shall be set to zero -- that is, $\underline{V}$ENT = 0. A flag setting of VM = 1 shall indicate that the acceleration due to venting is to be modeled. (Note that modeling of both venting and uncoupled thrusting is controlled by the same flag (VM).)

Corresponding to each of the MAX_NUM_VENT vent sources is a time line of its OFF-ON states. This information is stored in VENT ARRAY, the I-th row containing the NUM_VENT_I times at which the vent I changes state from OFF to ON or from ON to OFF. If the I-th vent (I = 1 to MAX_NUM_VENT) is ON at time T, then the vent vector is updated with the value of the acceleration for the I-th vent:

$\underline{V}ENT = \underline{V}ENT + \underline{V}ENT\_TABLE(I)$

where $\underline{V}$ENT_TABLE(I) contains the body-relative thrust vector for the I-th vent. If the I-th vent (I = 1 to MAX_NUM_VENT) is OFF, the value of $\underline{V}$ENT is not changed. Section 4.8 contains the details of the table lookup procedure for VENT_ARRAY and $\underline{V}$ENT_TABLE.

The uncoupled thrusting accelerations that occur during attitude maintenance caused by venting shall be incorporated into the total uncoupled thrusting acceleration vector as follows: If the I-th vent is ON at time T, the uncoupled thrusting vector, $\underline{R}$CS, shall be updated with the value of the uncoupled thrusting vector (in body coordinates) corresponding to the I-th vent:

$\underline{R}CS = \underline{R}CS + \underline{V}ENT\_DEP\_RCS(I)$

If the I-th vent is OFF, the value of RCS is not modified.

Besides trying to compensate for venting accelerations, the RCS thrusters operate to keep the shuttle at special attitude holds during certain phases of the missions. The special attitudes that have been identified are:

a) The vehicle's X body axis oriented along the local vertical (X-local-vertical hold);
b) The vehicle's Z body axis oriented along the local vertical (Z-local-vertical hold);
c) The three body axes make constant angles with the M50 coordinate axes (inertial hold);

d) The vehicle rotates with constant angular velocity about its X body axis, which is kept almost perpendicular to the Earth-Sun direction (inertial-with-rate or "barbecue" hold).

The inclusion in the equations of motion of the accelerations caused by the uncoupled thrusting of the RCS engines requires knowledge of the transformation matrix M that converts from body to M50 coordinates. This matrix is obtained in different ways, depending on whether it is to be used for prediction or propagation. Section 4.2.1.2 describes the computation of the matrix.

The computation of the RCS uncoupled thrusting acceleration vector in body coordinates shall be done as follows. The attitude hold maintained by the vehicle shall be identified, in the case of propagation, by comparing the appropriate columns of the M matrix with the unit position vector of the vehicle or of the Earth-Sun line, or by checking the shuttle's rotation rate. In the case of prediction, the attitude hold shall be identified by the values of a flag (ATT_FLAG), which have been prestored in a table in the form of a time line.

The four cases (one for each of the attitude holds described above) are:

1. If it is determined that the shuttle is maintaining a Z-local-vertical attitude hold, the total uncoupled thrusting acceleration

vector shall be updated with a premission-determined Z-local-vertical-hold uncoupled thrusting vector in body coordinates:

$$\underline{R}CS = \underline{R}CS + \underline{R}CS\_ZLV$$

The Z-local-attitude hold shall be indicated, for prediction, by ATT_FLAG = 3, and for propagation, by

$$EPS1 < |M_{1 \text{ to } 3,3} \cdot \underline{R}| \; R\_INV$$

where $\underline{R}$ is the position vector in M50 coordinates, M is the body to M50 transformation matrix, EPS1 is the Z-local-vertical hold tolerance, and R_INV is the reciprocal of the magnitude of $\underline{R}$.

2. If it is determined that the shuttle is maintaining an X-local-vertical attitude hold, the total uncoupled thrusting acceleration vector shall be updated with a premission-determined X-local-vertical-hold uncoupled thrusting vector in body coordinates:

$$\underline{R}CS = \underline{R}CS + \underline{R}CS\_XLV$$

The X-local-vertical attitude hold shall be indicated, for prediction, by the value ATT_FLAG = 4, and for propagation, by

$$EPS2 < |M_{1 \text{ to } 3,1} \cdot \underline{R}| \; R\_INV$$

where EPS2 is the X-local-vertical hold tolerance.

3. If it is determined that the shuttle is maintaining an inertial attitude hold, the total uncoupled thrusting acceleration vector shall be updated with a premission-determined inertial hold uncoupled thrusting vector in body coordinates:

$$\underline{R}CS = \underline{R}CS + \underline{R}CS\_INH$$

The inertial attitude hold shall be indicated, for prediction, by ATT_FLAG = 1, and for propagation, by

$$|\underline{WBR}| < EPS3$$

where $\underline{WBR}$ is the IMU-derived body rate in radians per second and EPS3 is the inertial hold tolerance.

4. If it is determined that the shuttle is maintaining an inertial-with-rate hold the total uncoupled thrusting acceleration shall be updated with a premission-determined inertial-with-rate uncoupled thrusting vector in body coordinates:

$$\underline{RCS} = \underline{RCS} + \underline{RCS\_BBQ}$$

The inertial-with-rate attitude hold shall be indicated, for prediction, by the value ATT_FLAG = 2, and for propagation by

$$|M_{1 \text{ to } 3,1} \cdot \underline{UR\_SUN}| < EPS4$$

where EPS4 is the inertial-with-rate tolerance.

The resulting uncoupled thrusting vector shall be incorporated into the total vent and uncoupled thrusting acceleration vector and rotated to M50 coordinates.

$\underline{V}$ENT_THRUST_BIAS is the body-relative estimated thrust acceleration bias vector.

When this acceleration bias vector is being estimated by the filter, the acceleration vector (also denoted as $\underline{V}$ENT) due to venting, uncoupled thrusting, and estimated acceleration bias is to be calculated as follows:

$$\underline{VENT} = M\ (\underline{VENT} + \underline{RCS} + \underline{VENT\_THRUST\_BIAS})$$

When the acceleration bias vector is not being estimated by the filter, the equation remains valid, but the vector $\underline{V}$ENT_THRUST_BIAS shall be set equal to 0 by the initialization software.

4.2.1.3 Integration of State Equations of Motion

Two sets of equations of motion shall be utilized for the propagation of the position and velocity vector of the orbiter. Each of these sets is accompanied by its own integration scheme.

During powered flight navigation phases, the equations used have the form of a Taylor series truncated at the term in h^3, where h is the step size. The integration scheme, called "Super-g", is an improved version of the average-g method, containing a corrector cycle. During phases in which short arcs of powered flight may be connected by short arcs of free flight, this integration method shall be in effect throughout. The only difference is that during the powered-flight arcs the non-gravitational accelerations shall be measured by the IMU's whereas in the free-flight arcs they shall be modeled.

During coasting flight navigation phases the equations of motion are to take the form of a variation-of-parameters method devised by S. Pines, where the parameters to be varied are the Cartesian initial conditions of the motion. The integration scheme to be used in connection with these equations is the Gill modification of the Runge-Kutta technique. This same scheme shall be utilized to propagate

the position and velocity vectors of the target vehicle during all rendezvous phases.

The following two subsections, 4.2.1.3.1 and 4.2.1.3.2 describe, respectively, the Super-g and the Precision integration algorithms.

4.2.1.3.1 Super-g

The Super-g integrator contains the following sequence of steps: it shall

1. Obtain, through its calling arguments, the flags required for invoking the acceleration function ACCEL_PERT_ONORBIT (that is, the degree and order of the gravitational potential, the drag mode, the vent mode and the attitude mode flag settings), the position and velocity vectors that are to be propagated, the time at which the new state is desired, the time interval of propagation and the difference between the current and the previous IMU accumulated sensed velocities (which could be zero). It shall internally rename these parameters respectively GD, GO, DFL, VFL, ATFL, R_SUP, V_SUP, T_CUR, DT and DV.

2. Advance the position vector with the use of the previous position and velocity vectors, the time interval DT, the acceleration vector GR_NEW saved from the previous cycle, and the value of DV:

   R_SUP = R_SUP + DT [V_SUP + .5 (DV + DT GR_NEW)]

3. Evaluate an intermediate modeled acceleration vector with the input flag settings, the new position vector, the previous velocity vector and the new time:

   GR_INT = ACCEL_PERT_ONORBIT (GD, GO, DFL, VFL, ATFL, R_SUP, V_SUP, T_CUR)

4. Introduce the central force term of the Earth's gravi-

tational attraction, which is not included in the ACCEL_PERT_ONORBIT function

$$\underline{GR\_INT} = \underline{GR\_INT} - EARTH\_MU\ \underline{R\_SUP}/|\underline{R\_SUP}|^3$$

5. Advance the velocity vector with the use of an average modeled acceleration and the sensed velocity change DV:

$$\underline{V\_SUP} = \underline{V\_SUP} + \underline{DV} + .5\ DT\ (\underline{GR\_INT} + \underline{GR\_NEW})$$

6. Correct the value of the position vector:

$$\underline{R\_SUP} = \underline{R\_SUP} + (\underline{GR\_INT} - \underline{GR\_NEW})\ DT^2/6.$$

7. Find a new value of the acceleration vector, based on the advanced position and velocity vectors and their time tag, including the central force term:

$$\underline{GR\_NEW} = \underline{ACCEL\_PERT\_ONORBIT}\ (GD, GO, DFL, VF, ATFL, \underline{R\_SUP}, \underline{V\_SUP}, T\_CUR)$$

$$\underline{GR\_NEW} = \underline{GR\_NEW} - EARTH\_MU\ \underline{R\_SUP}/|\underline{R\_SUP}|^3$$

The position and velocity vectors obtained constitute the required propagated state, and shall be placed in the out list of the integrator; G_NEW shall also be placed in the out list, for storage in a COMMON location where it can be accessed by Super-g for its next cycle, as well as by other users.

For details of the use of ACCEL_PERT_ONORBIT, see section 4.2.1.2.

4.2.1.3.2 Precision

This subfunction, which provides precision integration of the orbiter or target position/velocity state equations of motion during coasting flight, shall use a fourth-order Runge-Kutta numerical integration technique, modified with Gill's coefficients, in conjunction with an equations-of-motion formulation developed by S. Pines. Noncentral body accelerations shall be generated by the acceleration models (sec. 4.2.1.2) to account for perturbations due to drag, venting and uncoupled thrusting, and variations in the Earth's gravitational potential. The precision integration computational scheme shall be performed as follows:

1. Gravity (GMD and GMO), drag (DM), venting (VM), and vehicle-attitude (ATM) mode flags shall be obtained, together with the integration step size (DELTA_T), initial state and time ($\underline{R}$_IN, $\underline{V}$_IN, and T_IN), and final time at the end of the integration interval (T_FIN).
2. The final time shall be evaluated relative to the initial time to reset the step size (DT_STEP) to a positive or negative value, to permit forward or backward integration. If the final time (T_FIN) is less than the initial time (T_IN), then:

   DT_STEP = - DELTA_T

   Otherwise,

   DT_STEP = DELTA_T

3. Since the same Runge-Kutta-Gill integration technique shall be used for the state propagation and prediction functions, the Adams-Moulton flag (AM) is set to OFF, as only Runge-Kutta-Gill integration is performed for propagation. In addition, the integrator time shall be set to zero and the initial state vector shall be renamed for use in the Pines equations-of-motion formulation:

$$AM = OFF$$

$$T\_CUR = 0.$$

$$XN_{1 \text{ to } 3} = \underline{R\_IN}$$

$$XN_{4 \text{ to } 6} = \underline{V\_IN}$$

$$XN_7 = 0.$$

In the above equations, a seventh variable of integration (XN_7) is initialized to zero as required by the Pines technique. This seventh variable is the integrated initial time.

4. Next, the number of integration steps (N_STEPS) required for the input integration interval shall be calculated:

$$N\_STEPS = TRUNCATE\left(\frac{T\_FIN - T\_IN}{DT\_STEP}\right) + 1$$

5. The actual integration of the orbiter or target state equations (formulated according to the Pines technique) shall now be performed by proceeding as follows for each step in the integration interval. Note that, in the Pines equations-

-of-motion formulation, it is the initial conditions (R_IN, V_IN, and T_IN) that are integrated and then used in the closed-form solution of a two-body, unperturbed orbital problem using an F- and G-series type expression.

On each step, a check shall be made to evaluate the number (I) of the current step. If the integrator is on the final step (i.e., I = N_STEPS), then the integration step size (DT_STEP) shall be adjusted such that the last step will complete the integration to the final time:

DT_STEP = T_FIN - T_CUR - T_IN

The fourth-order Runge-Kutta-Gill integration technique shall then be invoked in conjunction with the Pines formulation as follows.

The Runge-Kutta-Gill integrator shall first save the initial integrator time of the current step:

T_STOR = T_CUR

Then, for each of four (i.e., J = 1 to 4) Runge-Kutta-Gill evaluations,

T_CUR = T_STOR + A_1 B_J DT_STEP

The Pines equations-of-motion formulation shall then be exercised to calculate the derivatives of the initial conditions (DERIV), and the Runge-Kutta-Gill integration is continued:

$$\left.\begin{array}{l} P = DT\_STEP\ DERIV_L \\ XN_L = XN_L + A_J\ (P - B_J\ Q_L) \\ Q_L = C_J\ P + D_J\ Q_L \end{array}\right\} L = 1 \text{ to } 7$$

where

A,B,C,D = premission-loaded arrays (J = 1 to 4) containing coefficients required for this formulation of the Runge-Kutta-Gill integration technique

XN = an array containing the seven variables of integration (i.e., integrated initial conditions)

DERIV = an array containing the total derivatives of the initial conditions at the current time.

The Pines formulations is evaluated as follows:

a. Several terms used in the F- and G-series calculations for the closed-form two-body equations are computed.

$$R\_IN = |XN_{1 \text{ to } 3}|$$

$$R\_IN\_INV = 1./R\_IN$$

$$SMA = 1./[2.\ R\_IN\_INV - (XN_{4 \text{ to } 6} \cdot XN_{4 \text{ to } 6})/EARTH\_MU]$$

$$C1 = SQRT(SMA)/SQR\_EMU$$

$$DELTAT = T\_CUR - XN_7$$

$$D\_IN = XN_{1 \text{ to } 3} \cdot XN_{4 \text{ to } 6}$$

b. The conic solution subfunction(F_AND_G) shall then be invoked to calculate several terms used in the computation of the conic velocity vector ($X_{4 \text{ to } 6}$) and the initial condition derivatives and compute the two-body conic position vector ($X_{1 \text{ to } 3}$) as follows (see section 4.2.7)

CALL: F_AND_G

IN LIST: SMA, DELTAT, C1, $XN_{1 \text{ to } 3}$, $\underline{0}$., R_IN_INV, 0., $XN_{4 \text{ to } 6}$, D_IN, 0.

OUT LIST: F, G, FDOT, GDOT, S0, S1, S2, S3, $X_{1 \text{ to } 3}$, R_FIN_INV, THETA

c. The two-body velocity vector shall then be computed:

$$X_{4 \text{ to } 6} = \text{FDOT } XN_{1 \text{ to } 3} + \text{GDOT } XN_{4 \text{ to } 6}$$

d. The perturbation accelerations shall now be calculated and several computations shall then be performed to compute perturbation derivatives for F- and G-series type terms for use in calculating the total derivatives of the seven variables of integration:

T_ACCEL = T_IN + T_CUR

$\underline{P}$ = ACCEL_PERT_ONORBIT (GMD, GMO, DM, VM, ATM, $X_{1 \text{ to } 3}$, $X_{4 \text{ to } 6}$, T_ACCEL)

D_TAU = $X_{1 \text{ to } 3} \cdot \underline{P}$

D_AUX = $X_{4 \text{ to } 6} \cdot \underline{P}$

$C2 = C1^2$ $\qquad$ C3 = 1./C2 $\qquad$ C4 = C2 D_AUX

S1 = C1 S1 S3 = SMA S2 C5 = C4 S1

S2 = C2 S2 S4 = 2. S3 D_AUX S5 = S2 D_TAU

DD = S1 C3 R_IN (SMA R_IN_INV-1.) + S0 D_IN

S6 = 2. S2 C4 DD + S5

R_IN_TAU = S4-C2 S1 D_AUX-S1 D_TAU

R_IN_AUX = R_IN_INV R_IN_TAU

F_TAU = S3 C3 R_IN_INV R_IN_AUX - S4

G_TAU = C5 R_IN - S6

FD_TAU = FDOT (C4-R_IN_AUX)

GD_TAU = S4 R_FIN_INV

e. Finally, the total derivatives of the variables of integration are to be computed as follows:

$$\text{DERIV}_{1 \text{ to } 3} = \text{GD\_TAU}\; X_{1 \text{ to } 3} - \text{G\_TAU}\; X_{4 \text{ to } 6} - G\,\underline{P}$$

$$\text{DERIV}_{4 \text{ to } 6} = -\text{FD\_TAU}\; X_{1 \text{ to } 3} + \text{F\_TAU}\; X_{4 \text{ to } 6} + F\,\underline{P}$$

$$\text{DERIV}_{7} = \text{S6} - 3.\ \text{C1 C4 SMA THETA} - \text{C5/R\_FIN\_INV}$$

6. After the required number of integration steps (N_STEPS) has been completed a final call shall be made to the Pines formulation to calculate the position and velocity vectors ($X_{1 \text{ to } 3}$ and $X_{4 \text{ to } 6}$) by applying the integrated initial conditions to the Pines equations defining the closed-form two-body solution.

7. Finally, the position and velocity vectors are to be renamed for output, and a new gravity acceleration vector (G_NEW) is to be calculated:

$\underline{R}$ FIN = $X_{1 \text{ to } 3}$

$\underline{V}$ FIN = $X_{4 \text{ to } 6}$

$\underline{G}$ NEW = $\underline{A}$CCEL_PERT_ONORBIT (GMD, GMO, DM, VM, ATM,

$\underline{R}$ FIN, $\underline{V}$ FIN, T_FIN) - EARTH_MU $\underline{R}$ FIN/|$\underline{R}$ FIN|^3

4.2.2 Covariance Matrix Propagation

The onorbit covariance matrix propagation subfunction will propagate the covariance matrix forward in time by using the state transition matrix. Additive process noise will be incorporated to account for unmodeled state and dynamic errors.

The transition matrix is broken into two parts - PHI, dimensioned 9 by 9 which corresponds to the first nine states (orbiter position and velocity and acceleration bias estimates) in the total transition matrix; and PHI_REND, dimensioned 10 by 10, which corresponds to the last ten states (target position and velocity, and rendezvous sensor bias estimates) in the total transition matrix and is used only during rendezvous. So the upper left 9 by 9 portion of the covariance matrix, E, is always propagated onorbit, but the rest of the covariance matrix is propagated only during rendezvous.

The propagation of the upper left 9 by 9 portion of E will be formulated for the free-flight phase differently than for the powered-flight phase. For free flight the full 9 by 9 portion will be propagated, defining uncertainties in position, velocity, and estimated acceleration biases. For powered flight, only the 6 by 6 portion of the covariance matrix associated with position and velocity uncertainties will be propagated.

The components of the state transition matrix are mathematically defined as the partials of the current state with re-

spect to the previous state. For free-flight phases, PHI will be formulated as shown in Figure 4.2.2-1.

$$PHI = \left[\begin{array}{cc|c} \multicolumn{2}{c|}{PHI_{1\ to\ 6,\ 1\ to\ 6}} & PHI_{1\ to\ 3,\ 7\ to\ 9} \\ \cline{3-3} & & PHI_{4\ to\ 6,\ 7\ to\ 9} \\ \hline 0_{3x3} & \multicolumn{1}{|c|}{0_{3x3}} & PHI_{7\ to\ 9,\ 7\ to\ 9} \end{array}\right]$$

Figure 4.2.2-1. State Transition Matrix Composition - Free Flight

This matrix is subdivided into the following submatrices:

1. A 6 by 6 submatrix, $PHI_{1\ to\ 6,\ 1\ to\ 6}$, composed of the orbiter position and velocity portion of the total transition matrix. This submatrix is calculated by the mean conic partials subfunction as described in section 4.2.8. The following assignments must be made.

   R_ONE = R_LAST

   V_ONE = V_LAST

   G_ONE = TOT_ACC_LAST

   R_TWO = R_FILT

   V_TWO = V_FILT

   G_TWO = TOT_ACC

   DELTIM = DT_FILT

   Then after the mean conic partials subfunction has executed:

   $PHI_{1\ to\ 6,\ 1\ to\ 6}$ = PHI_MC.

2. A 6 by 3 submatrix, $PHI_{1\ to\ 6,\ 7\ to\ 9}$, composed of two 3 by 3 matrices, that correlates the position and velocity

with the estimated bias accelerations.

Where

$$\left.\begin{aligned} PHI_{J+3,\ I+6} &= M\_SBODYM50_{J,I} DIAG_I \\ PHI_{J,\ I+6} &= M\_SBODYM50_{J,I} TAU\_VENT_I (DT\_FILT \\ &\qquad - DIAG_I) \end{aligned}\right\} \quad \begin{aligned} \text{for } I &= 1 \text{ to } 3 \\ J &= 1 \text{ to } 3 \end{aligned}$$

where

$$DIAG_I = TAU\_VENT_I\ (1. - PHI_{I+6,\ I+6})$$

3. A 3 by 3 diagonal submatrix, $PHI_{7 \text{ to } 9,\ 7 \text{ to } 9}$, that represents the bias portion of the transition matrix.

   Where

$$PHI_{I+6,\ I+6} = e^{-DT\_FILT/TAU\_VENT_I} \quad (\text{for } I = 1 \text{ to } 3)$$

4. Two 3 by 3 null matrices.

The state noise covariance matrix, S, shall be formulated as shown in Figure 4.2.2-2. This matrix is to be used to account for unmodeled state errors and uncertainty in unmodeled accelerations.

$$S = \left[\begin{array}{c|c|c} S_{1 \text{ to } 3,\ 1 \text{ to } 3} & S_{1 \text{ to } 3,\ 4 \text{ to } 6} & 0_{3x3} \\ \hline S_{4 \text{ to } 6,\ 1 \text{ to } 3} & S_{4 \text{ to } 6,\ 4 \text{ to } 6} & 0_{3x3} \\ \hline 0_{3x3} & 0_{3x3} & S_{7 \text{ to } 9,\ 7 \text{ to } 9} \end{array}\right]$$

Figure 4.2.2-2. State Noise Covariance Matrix Composition - Free Flight

The entries in Figure 4.2.2-2 will be defined as follows:

$$S_{4\text{ to }6,\ 4\text{ to }6} = \underline{D}IAG\ \underline{D}IAG^T$$

where

$$\underline{D}IAG = DT\_FILT\ D\_COE\_PCT\_ERR\ \underline{D}$$

$$S_{4\text{ to }6,\ 1\text{ to }3} = 0.5\ DT\_FILT\ S_{4\text{ to }6,\ 4\text{ to }6}$$

$$S_{1\text{ to }3,\ 4\text{ to }6} = S_{4\text{ to }6,\ 1\text{ to }3}$$

$$S_{1\text{ to }3,\ 1\text{ to }3} = 0.5\ DT\_FILT\ S_{4\text{ to }6,\ 1\text{ to }3}$$

$$S_{I+6,\ I+6} = TAU\_VENT_I\ VAR\_VENT\_DT\ (1.\ -PHI^2_{I+6,\ I+6})$$

for I = 1 to 3

The covariance matrix, E, will then be propagated by the following equation:

$$E_{1\text{ to }9,\ 1\text{ to }9} = PHI\ E_{1\text{ to }9,\ 1\text{ to }9}\ PHI^T + S$$

The powered-flight phase will be indicated by the PWRD_FLT_NAV parameter being set to ON. During this phase, the covariance matrix will be propagated by the following equation:

$$E_{1\text{ to }6,\ 1\text{ to }6} = PHI_{1\text{ to }6,\ 1\text{ to }6}E_{1\text{ to }6,\ 1\text{ to }6}PHI^T_{1\text{ to }6,\ 1\text{ to }6} + S_{1\text{ to }6,\ 1\text{ to }6}$$

The 6 by 6 matrix, $PHI_{1\text{ to }6,\ 1\text{ to }6}$, will be defined as being identical to the free-flight phase.

The 6 by 6 state noise matrix, $S_{1\text{ to }6,\ 1\text{ to }6}$, will be formulated as follows: First, the misalinement errors are accounted for by

$$S_{4\text{ to }6,\ 4\text{ to }6} = \left[\begin{array}{c|c|c} \begin{array}{l} DV\_FILT_3^2\ DIAG_2 \\ +\ DV\_FILT_2^2\ DIAG_3 \end{array} & -DV\_FILT_1\ DV\_FILT_2\ DIAG_3 & -DV\_FILT_1\ DV\_FILT_3\ DIAG_2 \\ \hline -DV\_FILT_1\ DV\_FILT_2\ DIAG_3 & \begin{array}{l} DV\_FILT_1^2\ DIAG_3 \\ +\ DV\_FILT_3^2\ DIAG_1 \end{array} & -DV\_FILT_2\ DV\_FILT_3\ DIAG_1 \\ \hline -DV\_FILT_1\ DV\_FILT_3\ DIAG_2 & -DV\_FILT_2\ DV\_FILT_3\ DIAG_1 & \begin{array}{l} DV\_FILT_1^2\ DIAG_2 \\ +\ DV\_FILT_2^2\ DIAG_1 \end{array} \end{array}\right]$$

$S_{1\text{ to }3;\ 4\text{ to }6} = 0.5\ DT\_FILT\ S_{4\text{ to }6,\ 4\text{ to }6}$

$S_{4\text{ to }6,\ 1\text{ to }3} = S_{1\text{ to }3,\ 4\text{ to }6}$

$S_{1\text{ to }3,\ 1\text{ to }3} = .5\ DT\_FILT\ S_{1\text{ to }3,\ 4\text{ to }6}$

where

$DIAG_I = VAR\_IMU\_ALIGN_I + (T\_LAST\_FILT - T\_ALIGN)^2\ VAR\_IMU\_DRIFT_I$ (for I = 1 to 3)

The accelerometer errors are then accounted for by

$$\left.\begin{aligned}
S_{I,\,I} &= S_{I,\,I} + \text{NOISE_R} \\
S_{I+3,\,I+3} &= S_{I+3,\,I+3} + \text{NOISE} \\
S_{I+3,\,I} &= S_{I+3,\,I} + \text{NOISE_RV} \\
S_{I,\,I+3} &= S_{I+3,\,I}
\end{aligned}\right\} \text{(for I = 1 to 3)}$$

where

$$\text{NOISE} = \text{VAR\_ACC\_QUANT} + (\text{VAR\_UNMOD\_ACC\_DT})\ \ \text{DT\_FILT}$$

$$\text{NOISE\_R} = \text{NOISE}\ (\text{DT\_FILT})^2\ \ 0.25$$

$$\text{NOISE\_RV} = \text{NOISE}\ (\text{DT\_FILT})\ 0.5$$

During rendezvous the rest of the covariance matrix must be propagated. This is accomplished by using a 10 by 10 state transition matrix PHI_REND, formulated as shown in figure 4.2.2-3.

$$\text{PHI_REND} = \left[\begin{array}{c|c}
\text{PHI_REND}_{1\text{ to }6,\ 1\text{ to }6} & 0_{3\text{x}6} \\
\hline
0_{3\text{x}6} & \text{PHI_REND}_{7\text{ to }10,\ 7\text{ to }10}
\end{array}\right]$$

Figure 4.2.2-3. State transition matrix-rendezvous.

This matrix is subdivided into the following submatrices:

1. A 6x6 submatrix, $\text{PHI\_REND}_{1\text{ to }6,\ 1\text{ to }6}$, composed of the target position and velocity portion of the total transition matrix. The submatrix is calculated by the mean conic partials subfunction as described in section 4.2.8. The following assignments must be made.

   $\underline{\text{R}}\text{\_ONE} = \underline{\text{R}}\text{\_TV\_LAST}$

V_ONE = V_TV_LAST

G_ONE = G_TV_LAST

R_TWO = R_TV

V_TWO = V_TV

G_TWO = G_TV

DELTIM = DT_FILT

Then after the mean conic partial subfunction has executed:

$$\text{PHI\_REND}_{1 \text{ to } 6,\ 1 \text{ to } 6} = \text{PHI\_MC}$$

2. A 4x4 submatrix, $\text{PHI\_REND}_{7 \text{ to } 10,\ 7 \text{ to } 10}$, composed of the sensor bias portion of total transition matrix. Where

$$\text{PHI\_REND}_{I+6,\ I+6} = e^{-\text{DT\_FILT}/\text{TAU\_SENS}_I} \quad (\text{for } I = 1 \text{ to } 4)$$

The state noise matrix is formulated for rendezvous as follows.

$$\text{S\_REND}_{I+6,\ I+6} = \text{TAU\_SENS}_I\ \text{VAR\_SENS\_DT}_I\ (1 - \text{PHI\_REND}^2_{I+6,\ I+6}) \quad (\text{for } I = 1 \text{ to } 4)$$

The rest of S_REND is zero.

The remainder of the covariance matrix is propagated as follows.

$$E_{10 \text{ to } 19,\ 10 \text{ to } 19} = \text{PHI\_REND}\ E_{10 \text{ to } 19,\ 10 \text{ to } 19}\ \text{PHI\_REND}^T + \text{S\_REND}$$

$$E_{1 \text{ to } 9,\ 10 \text{ to } 19} = \text{PHI}\ E_{1 \text{ to } 9,\ 10 \text{ to } 19}\ \text{PHI\_REND}^T$$

Finally the entire 19 by 19 covariance matrix is made symmetric.

$$E_{J,\,I} = E_{I,\,J} \quad (\text{ for } I = 1,\ 18;\ J = I + 1,\ 19)$$

4.2.3 State Vector Interpolation

The state vector interpolation subfunction shall provide the approximate position, velocity and acceleration of either the orbiter or the target at a specified time within a given propagation interval, at both ends of which these vectors are known.

The time at which the vectors are desired is the time of an external sensor measurement, and the purpose of the interpolation is to enable the navigation filter to calculate the measurement residuals at that time.

The method utilized for the interpolation shall consist of defining a mean conic on the basis of the positions and velocities of the vehicle in question at both ends of the propagation interval, and obtaining the desired vectors as if the vehicle moved along this mean conic. That is, a calculation shall be made to determine the point on the mean conic corresponding to the time of the measurement, and the velocity and position of such a point shall be taken as the state of the vehicle.

If the time of the measurement is very close to the final time of the propagation interval (that is, within a tolerance that depends on the type of sensor utilized) the position, velocity and time tag will be taken as those of the final time.

The modeled acceleration shall be obtained by invoking the acceleration function with the position, velocity, and time (determined by this process) in the calling arguments, and adding the central force term. The sensed acceleration shall be found by dividing the difference in accumulated sensed velocities at both ends of the propagation interval by the duration of the interval. The total acceleration will be the sum of these two.

In more detail, the state vector interpolation subfunction shall be invoked with a calling list that contains

- R_ONE, V_ONE — position and velocity of the vehicle at the previous propagation step;
- R_TWO, V_TWO, T_TWO — current position, velocity and time tag;
- V_IMU_DIF — difference between IMU accumulated sensed velocities at the current time and at the previous time;
- T_DIF — duration of the propagation interval;
- SENSOR_ID — identifier of the sensor used for the measurement in question;
- DTGO — difference between the current time and the measurement time;
- IGD, IGO, IDM, IVM, IATM — flags for the call to the acceleration function ACCEL_PERT_ONORBIT (see section 4.2.1.2 for details of these flags).

Then, the following steps shall be taken

1. A local variable, DELTAT, shall take the place of DTGO with a negative sign (to propagate backwards from the current filter time, along the mean conic)

   DELTAT = -DTGO

2. A check of the absolute value of DELTAT against the tolerance corresponding to the sensor type will be performed

   $|\text{DELTAT}| \leq \text{EPS\_TIME}_{\text{SENSOR\_ID}}$

   2.1 If it is found that DELTAT in absolute value is less than the tolerance, the values of the position and velocity of the vehicle at the current time shall be used as the state at the measurement time; the time tag at the measurement instant shall also be set equal to the current time:

   R_RESID = R_TWO

   V_RESID = V_TWO

   T_RESID = T_TWO

   2.2 If, on the other hand, the difference between the time of the measurement and the current time exceeds the tolerance, perform the following:

   2.2.1 Certain parameters associated with the mean conic shall be obtained

   R_TWO_INV = 1./|R_TWO|

   SMA = 1./[1./|R_ONE| + R_TWO_INV -(V_ONE·V_ONE + V_TWO·V_TWO)/(2.·EARTH_MU)]

C1 = SQRT (SMA)/SQR_EMU

D_TWO = R_TWO·V_TWO C1/SMA

and the time tag of the state vector at measurement shall be set;

T_RESID = T_TWO + DELTAT

2.2.2 The F and G series subfunction shall then be called (see section 4.2.7 for the description of this subfunction)

CALL: F_AND_G

IN LIST: SMA, DELTAT, C1, R_TWO, 0., 0., 0., R_TWO_INV, 0., V_TWO, D_TWO, 0.

OUT LIST: F, G, FDOT, GDOT, S0, S1, S2, S3, R_RESID, R_FIN_INV, THETA

The position vector (R_RESID) comes out of this call; the velocity vector (V_RESID) does not, but it can be calculated on the basis of FDOT and GDOT, which are also obtained from the F and G series call:

V_RESID = FDOT R_TWO + GDOT V_TWO

3. Finally, the acceleration vector shall be obtained.

A_RESID = -EARTH_MU R_RESID/|R_RESID|^{3} + ACCEL_PERT

ONORBIT (IGD, IGO, IDM, IVM, IATM, R_RESID, V_RESID, T_RESID) + V_IMU_DIF/T_DIF

A suggested implementation of this subfunction may be found in Appendix B, with the name ONORBIT_SV_INTERP.

4.2.4 State and Covariance Measurement Incorporation (Kalman Filter)

This subfunction shall use a Kalman filter to incorporate the measurement data to update the covariance matrix and the state vector. To perform these tasks, the Kalman filter uses the covariance matrix, measurement partials, measurement residual, and the priori measurement variance.

If the measurement data have been judged valid and the proper measurement subfunction has been executed, the following update equations are to be computed. (Note: The measurement subfunction generates the partial vector, the residual, and the a priori variance.)

First, the scalar quantity BT_E_B is to be calculated from the covariance matrix E and vector measurement partials $\underline{B}$

$$\underline{\text{EB\_COPY}} = E\ \underline{B}$$

$$\text{BT\_E\_B} = \underline{B} \cdot \underline{\text{EB\_COPY}}$$

where the second equation requires a dot product. The partials vector $\underline{B}$ shall then be set equal to zero so that subsequent measurement subroutines will only be required to calculate non-zero elements. The quantity MS_DELQ, which represents the expected variance in the measurement, is then to be computed by

$$\text{MS\_DELQ} = \text{BT\_E\_B} + \text{VAR}$$

A residual edit shall then be performed. The EDIT_FLAG is to be set to "ON" to inform the crew if the edit fails - that is, if the square of the residual is greater than the quantity RESID_TEST, where RESID_TEST = K_RES_EDIT MS_DELQ and K_RES_EDIT is a premision constant; otherwise the flag is set to "processed". However, the residual edit is overridden or inhibited, when the manual edit override for the particular sensor being processed is active. This results in measurement incorporation, and the edit flag is set to "FORCED".

If there is no edit or if a "force" exists, the subfunction shall then compute the Kalman filter gain,

$$\underline{\text{OMEGA}} = \underline{\text{EB}}\text{\_COPY/MS\_DELQ}$$

and update the covariance matrix,

$$\text{E} = \text{E} - \underline{\text{OMEGA}}\ \underline{\text{EB}}\text{\_COPY}$$

where the implied multiplication of the two vectors denotes the dyadic or "outer" product. This subfunction shall update the state vector by application of the following equations:

$$\underline{\text{R}}\text{\_FILT} = \underline{\text{R}}\text{\_FILT} + \underline{\text{OMEGA}}_{\text{1 to 3}}\ \text{DELQ}$$

$$\underline{\text{V}}\text{\_FILT} = \underline{\text{V}}\text{\_FILT} + \underline{\text{OMEGA}}_{\text{4 to 6}}\ \text{DELQ}$$

$$\underline{\text{VENT}}\text{\_THRUST\_BIAS} = \underline{\text{VENT}}\text{\_THRUST\_BIAS} + \underline{\text{OMEGA}}_{\text{7 to 9}}\ \text{DELQ}$$

$$\underline{\text{R}}\text{\_TV} = \underline{\text{R}}\text{\_TV} + \underline{\text{OMEGA}}_{\text{10 to 12}}\ \text{DELQ}$$

$$\underline{\text{V}}\text{\_TV} = \underline{\text{V}}\text{\_TV} + \underline{\text{OMEGA}}_{\text{13 to 15}}\ \text{DELQ}$$

$$\underline{S}ENSOR\_BIAS = \underline{S}ENSOR\_BIAS + \underline{O}MEGA_{16 \text{ to } 19}\ DELQ,$$

where DELQ corresponds to the appropriate measurement residual. The edit flag corresponding to the appropriate measurement subfunction is then to be set to indicate that the measurement data have been processed rather than edited.

This subfunction shall also be used to compute the residual test quantity for manually selected sensor types whenever the filter is not incorporating data. This quantity, together with residuals calculated by the measurement subfunctions, is required for display purposes. A flag corresponding to the appropriate measurement type shall be set by the navigation sensor selection task to prevent Kalman filter gain computations and state and covariance matrix updates under this condition. The filter edit flag shall be set to "STAT", in this case, to indicate to Measurement Processing Statistics (sec. 4.3.2.8) that the data have been computed for display purposes only.

It is required that the residual, the residual test quantity (RESID_TEST), and the residual edit flag corresponding to each measurement subfunction be saved for display purposes.

4.2.5 Ground Updates (auto inflight)

The auto inflight update task shall perform the following functions for orbiter and/or target vehicles:

1. Initialize onboard position and velocity state vectors to uplinked M1950 whole vectors, predicted to current time;
2. Initialize the onboard filter covariance matrix using prestored (or uplinked) position and velocity standard deviations and correlation coefficients (in UVW coordinate system), and using prestored covariance values for unmodeled acceleration bias error (in body coordinate system).

This task shall be available during both onorbit and rendezvous navigation phases, and shall be performed as follows:

1. A flag, DO_AUTO_UPDATE, shall be tested once per navigation cycle to determine whether an update shall be performed. If such an update is to occur (DO_AUTO_UPDATE = ON, as set by the ground uplink processor), then the update process shall be performed as specified by the remaining steps, below. If an update is not to occur (DO_AUTO_UPDATE = OFF), then a second flag (DID_AUTO_UPDATE) shall be maintained in an OFF status.

2. If the DO_AUTO_UPDATE flag is ON, then an orbiter vehicle uplink flag (OV_UPLINK) is tested to see if the uplinked data pertains to the orbiter vehicle

OV_UPLINK = ON, orbiter data uplinked

OV_UPLINK = OFF, no orbiter data uplinked

If orbiter data has been uplinked, then the following shall be performed to reinitialize the onboard orbiter state vector and associated covariance matrix

a. set the upper left 9x9 portion of the covariance matrix to zero

$$E_{1 \text{ to } 9,\ 1 \text{ to } 9} = 0.$$

b. if in a rendezvous navigation phase (i.e., if REND_NAV_FLAG = ON) then all correlation terms between orbiter position/velocity/unmodeled-acceleration bias and the remaining elements of the 19x19 rendezvous covariance matrix shall be zeroed

$$E_{1 \text{ to } 9,\ 10 \text{ to } 19} = 0.$$

$$E_{10 \text{ to } 19,\ 1 \text{ to } 9} = 0.$$

c. predict the uplinked position and velocity vectors ($\underline{R}$_GND, $\underline{V}$_GND) at time T_GND, to current time (T_CURRENT_FILT) by use of the onorbit precision state prediction principal function

CALL: ONORBIT_PREDICT

IN LIST: GM_DEG, GM_ORD, DRAG_MODE_NAV,
VENT_MODE_NAV, 1, PREC_STEP, R_GND,
V_GND, T_GND, T_CURRENT_FILT

OUT LIST: R_FILT, V_FILT

Section 4.5.2 describes the requirements for setting the parameters GM_DEG, GM_ORD, DRAG_MODE_NAV, VENT_MODE_NAV and PREC_STEP, for orbiter state prediction.

d. initialize the orbiter position/velocity 6x6 covariance submatrix from prestored (or uplinked) standard deviations and correlation coefficients in UVW coordinates by use of the covariance initialization subfunction described in section 4.2.9

CALL: ONORBIT_COVINIT_UVW

IN LIST: SIG_UPDATE, COV_COR_UPDATE,
R_FILT, V_FILT

OUT LIST: $E_{1 \text{ to } 6,\ 1 \text{ to } 6}$

e. initialize the 3x3 covariance submatrix (diagonal elements) to prestored values (in body-axis coordinates), and zero the corresponding state vector elements

$$\left.\begin{array}{l} E_{I+6,\ I+6} = \text{COV\_ACCEL\_BODY\_INIT}_I \\ \text{VENT\_THRUST\_BIAS}_I = 0. \end{array}\right\} \text{for } I = 1 \text{ to } 3$$

f. compute the total orbiter acceleration vector at current time for use in the state propagation subfunction,

$$\underline{\text{TOT\_ACC}} = \underline{\text{ACCEL\_PERT\_ONORBIT}} (\text{GM\_DEG}, \text{GM\_ORD}, 1,1,0, \underline{\text{R}}\_\text{FILT}, \underline{\text{V}}\_\text{FILT}, \text{T\_CURRENT\_FILT}) - \text{EARTH\_MU}\ \underline{\text{R}}\_\text{FILT}/|\underline{\text{R}}\_\text{FILT}|^3$$

g. and, finally, the OV_UPLINK flag shall be set to OFF.

Next (whether or not orbiter data had been uplinked), the target vehicle uplink flag (TV_UPLINK) shall be tested in determining whether the uplinked data pertains to the target vehicle

TV_UPLINK = ON, target data uplinked

TV_UPLINK = OFF, no target data uplinked

If target data has been uplinked, then the following shall be performed to re-initialize the onboard target state vector and associated covariance matrix.

a. if in a rendezvous navigation phase (i.e., if REND_NAV_FLAG = ON) zero the lower right covariance submatrix pertaining to the target vehicle position and velocity vectors, and the rendezvous sensor systematic biases... and also zero all correlation terms (covariance elements) between orbiter-position-velocity-unmodeled-acceleration and target-position-velocity-sensor-systematic-bias

$$E_{10 \text{ to } 19,\ 10 \text{ to } 19} = 0.$$

$$E_{1 \text{ to } 9,\ 10 \text{ to } 19} = 0.$$

$$E_{10 \text{ to } 19,\ 1 \text{ to } 9} = 0.$$

b. also, predict the uplinked position and velocity vector (R_TV_GND, V_TV_GND) at time T_TV_GND, to current time (T_CURRENT_FILT) by use of the onorbit precision state prediction principal function

CALL: ONORBIT_PREDICT

IN LIST: GM_DEG, GM_ORD, DRAG_MODE_NAV, 0, 3, PREC_STEP, R_TV_GND, V_TV_GND, T_TV_GND, T_CURRENT_FILT

OUT LIST: R_TV, V_TV

Section 4.5.2 describes the requirements for setting the parameters GM_ORD, GM_DEG, DRAG_MODE_NAV and PREC_STEP for target state vector prediction.

c. initialize the target position/velocity 6x6 covariance submatrix from prestored (or uplinked) standard deviations and correlation coefficients in UVW coordinates, by use of the covariance initialization subfunction described in section 4.2.9

CALL: ONORBIT_COVINIT_UVW

IN LIST: SIG_TV_UPDATE, COV_COR_TV_UPDATE, R_TV, V_TV

OUT LIST: $E_{10 \text{ to } 15,\ 10 \text{ to } 15}$

d. finally, compute the total target acceleration vector at current time for use in the state propagation subfunction,

$\underline{G}$_TV = ACCEL_PERT_ONORBIT (GM_DEG, GM_ORD, DRAG_MODE_NAV, 0, 3, PREC_STEP, $\underline{R}$_TV, $\underline{V}$_TV, T_CURRENT_FILT) - EARTH_MU $\underline{R}$_TV/|$\underline{R}$_TV|^3

e. if not in a rendezvous navigation phase (see a., above), then the uplinked target vehicle data shall be stored for use in a rendezvous phase

$\underline{R}$_TV = $\underline{R}$_TV_GND

$\underline{V}$_TV = $\underline{V}$_TV_GND

T_TV = T_TV_GND

f. next, whether in a rendezvous navigation phase or not, a flag (TARG_VEC_AVAIL) shall be set to ON indicating the existence of a target vector (for later use by the orbit/rendezvous navigation sequencer principal function in initializing the target state)

TARG_VEC_AVAIL = ON

and, finally the TV_UPLINK flag shall be set to OFF, indicating that the target uplink re-initialization has been completed.

3. Once orbiter and/or target state and covariance matrices have been re-initialized, the following shall be performed:

a. if in a rendezvous navigation phase (i.e., if REND_NAV_FLAG = ON), set all sensor processing flags to the OFF state

DO_RR_ANGLES_NAV_LAST = OFF

DO_RRDOT_NAV_LAST = OFF

DO_ST_ANGLES_NAV_LAST = OFF

DO_COAS_ANGLES_NAV_LAST = OFF

b. regardless of whether in a rendezvous navigation phase or not, a different flag (DID_AUTO_UPDATE) shall be set to the ON state for transmittal back to the ground uplink processor; this setting indicates the update has been performed (orbiter and/or target).

4. If no update (either orbiter or target) is to be performed (i.e., the DO_AUTO_UPDATE flag was tested and found to be in the OFF state) then the flag (DID_AUTO_UPDATE) shall be maintained as OFF.

The first flag (DO_AUTO_UPDATE) shall be reset to OFF by the ground uplink processor before the next navigation cycle.

4.2.6 Angle Measurement Partials

The angle measurement partials common subfunction computes the measurement partials for an angle type measurement during rendezvous navigation.

The angle measurement partial vector is computed with the following equations.

$$\underline{R}\_RHO = \underline{R}\_TV\_RESID - \underline{R}\_RESID$$

$$\underline{RHO}\_PLANE = \underline{R}\_RHO - (\underline{R}\_RHO \cdot \underline{I}\_N)\ \underline{I}\_N$$

$$\underline{B}\_TEMP = UNIT\ (\underline{RHO}\_PLANE \times \underline{I}\_N)/|\underline{RHO}\_PLANE|$$

$$\underline{B}_{1\ to\ 6} = (PHI\_PATCH_{1\ to\ 3,\ 1\ to\ 6})^T \underline{B}\_TEMP$$

$$\underline{B}_{10\ to\ 15} = -(PHI\_REND\_PATCH_{1\ to\ 3,\ 1\ to\ 6})^T \underline{B}\_TEMP$$

$$\underline{B}_{16\ to\ 17} = 0.$$

where the unit vector $\underline{I}\_N$ corresponds to the appropriate row of the mean of 50 to sensor transformation matrix for the measurement being processed and PHI_PATCH and PHI_REND_PATCH are transition matrices formulated as part of the state interpolation process.

4.2.7 Conic Solution (F and G Series)

The conic solution subfunction, utilized by the state vector interpolation, position-velocity submatrix of state transition matrix, and precision integration subfunctions shall provide the capability to trace the progress of a point along its orbit assuming pure Keplerian motion, by means of the F and G series algorithm in terms of the eccentric anomaly.

The variables F and G, $\dot{F}$ and $\dot{G}$ shall be calculated as functions of the difference in eccentric anomaly between an initial time at which a position and a velocity vector are known and a final time at which they are required.

If the final position and velocity are known, the difference in eccentric anomaly can be easily calculated and the F, G, $\dot{F}$ and $\dot{G}$ expressions can be obtained with the use of certain auxiliary variables called here S0, S1, S2, and S3.

If the final position and velocity are not known but only the transfer time, it is necessary to solve a form of Kepler's equation to obtain the difference in eccentric anomaly.

The conic solution subfunction shall have the following calling arguments:

SMA - semi major axis of the conic,

DELTAT - transfer time,

C1 - an auxiliary constant, equal to the square root

of SMA divided by the square root of the Earth's gravitational constant,

R_IN - the initial position vector (M1950),

R_FIN - the final position vector (M1950) (if unknown, a zero vector shall be input),

R_IN_INV - the reciprocal of the magnitude of R_IN,

R_RIN_INV - the reciprocal of the magnitude of R_FIN (if unknown, a zero shall be input),

V_IN - the initial velocity vector (M1950)

D_IN - the dot product of the initial position and velocity vectors, and

D_FIN - the dot product of the final position and velocity vectors (if unknown, a zero shall be input).

The conic solution subfunction shall then perform the following:

1. Check the value of R_FIN_INV to see if Kepler's equation is to be solved.

1.1 If R_FIN_INV ≠ 0., which indicates that the final position vector is already known, the difference in eccentric anomaly shall be obtained from the expression

THETA = (C1(D_FIN-D_IN) + DELTAT/C1)/SMA

1.2 If R_FIN_INV = 0., the final position vector is to be calculated. This requires solving a modified form of Kepler's equation, which shall be accomplished by an iterative process that consists of the following steps:

1.2.1 Two auxiliary quantities shall be obtained from the input data:

ONEMRIN = (SMA - 1./R_IN_INV)/SMA

D_MN_AN = DELTAT/(C1 SMA)

D_MN_AN is the difference in mean anomaly, which shall be taken as a first approximation to the difference in eccentric anomaly, THETA. A correction to this quantity, THETA_COR, shall be set at a high value to begin the iteration:

THETA = D_MN_AN

THETA_COR = 10.

1.2.2 Then THETA and THETA_COR shall be recalculated until THETA_COR becomes smaller than a given tolerance:

DO UNTIL

THETA_COR $\leq$ EPS_DEP,

by repeatedly evaluating the equations

S0 = COS (THETA)

S1 = -SIN (THETA)

S2 = 1. -S0

ERR = D_NM_AN-THETA-D_IN S2 + ONEMRIN S1

THETA_COR = ERR/(1. + D_IN S1 - ONEMRIN S0)

THETA = THETA + THETA_COR

2. When the difference in eccentric anomaly is determined, certain auxiliary variables shall be calculated

S0 = COS (THETA)

S1 = SIN (THETA)

S2 = 1. -S0

S3 = THETA - S1

2. The values of F and G shall then be determined:

F = 1. - SMA S2 R_IN_INV

G = DELTAT - C1 SMA S3

4. If the final position vector and the reciprocal of its magnitude were not known, they shall be calculated:

   IF R_FIN_INV = 0., then set

   R_FIN = F R_IN + G V_IN

   R_FIN_INV = 1./|R_FIN|

5. The functions $\dot{F}$ and $\dot{G}$, required for the calculation of the final velocity vector, shall be evaluated:

   FDOT = -EARTH_MU C1 S1 R_IN_INV R_FIN_INV

   GDOT = 1. - SMA S2 R_FIN_INV

Finally, the out list of the conic solution subfunction shall contain the following quantities, (different users require different sets of these):

F, G, DOT, GDOT, S0, S1, S2, S3, R_FIN, R_FIN_INV, THETA

A suggested implementation, in the form of a detailed flow chart, may be found in Appendix B, under the name F_AND_G.

4.2.8 Position - Velocity Submatrix of State Transition Matrix

This subfunction computes a 6x6 submatrix (PHI_MC) of a larger state transition matrix. PHI_MC is the partial derivative of the new position - velocity state with respect to the old position velocity state.

A formulation is used which assumes that a mean conic section may be used to describe the path taken between the initial position and velocity ($\underline{R}$_ONE and $\underline{V}$_ONE) at initial total acceleration ($\underline{G}$_ONE) and the final position and velocity ($\underline{R}$_TWO and $\underline{V}$_TWO) at final total acceleration ($\underline{G}$_TWO) over a time step DELTIM. The ergodic semi-major axis SMA, is computed by using the average of the reciprocal of the semi-major axis derived from combinitation of the respective vis-viva computations at the initial and final orbital states, and is given by:

$$SMA = 1./(1./|\underline{R}\_ONE| + 1./|\underline{R}\_TWO| -(|\underline{V}\_ONE|^2 + |\underline{V}\_TWO|^2)/2.\ EARTH\_MU).$$

where EARTH_MU is the earths gravitational constant. The Stumpff constant, C1, predicated on the mean conic semi-major axis, is computed by:

$$C1 = \sqrt{SMA/EARTH\_MU}$$

Then the Kepler subfunction, F_AND_G, is called by supplying

SMA,

DELTAT = DELTIM,

C1,

R_IN = R_ONE,

R_FIN = R_TWO

R_IN_INV = 1./|R_ONE|

R_FIN_INV = 1./|R_TWO|,

V_IN = V_ONE,

D_IN = R_ONE·V_ONE, and

D_FIN = R_TWO·V_TWO,

in that order

The Kepler subfunction returns the output F, G, FDOT, GDOT, S0, S1, S2, and S3. For this case R_TWO and R_TWO_INV are not updated since R_TWO_INV is supplied as a non-zero quantity. However THETA, the eccentric anomaly angle is generated as an output in any case.

After computing certain auxillary constants such as

FM1 = F-1.,

GDM1 = GDOT-1.,

S1 = C1 S1,

C2 = C1^{2},

CONST = (C1 C2 THETA (2. + S0) - 3. C2 S1) SMA, and

S2 = C2 S2,

which represent common functionals and Stumpff series summa-

tions for circular or elliptical orbits; the partial derivatives may now be calculated. The following equations for the partial derivatives are written algebracially for clarity, (Figure 4.2.8-1), with R_o representing R_ONE, R representing R_TWO, $\dot{R}_o$ representing V_ONE, $\dot{R}$ representing V_TWO, $\ddot{R}_o$ representing G_ONE, $\ddot{R}$ representing G_TWO, f representing F, g representing G, $\dot{f}$ representing FDOT, $\dot{g}$ representing GDOT and U representing CONST, as well as having lower case letters representing the scalar magnitude of the respective upper case letter vectors.

Certain recurring groups of symbols may be collected to facilitate ease of coding and minimization of error. (See the flow chart MEAN_CONIC_PARTIAL_TRANSITION_MATRIX_6X6 in Appendix B). Each 3X3 submatrix of the 6X6 matrix PHI_MC results from the summation of 3X3 matrices generated by the dyadic product of groups of vectors of length three.

$$\text{PHI\_MC}_{1\text{ to }3,\ 1\text{ to }3} = \frac{\partial R}{\partial R_o} = \left[\frac{\dot{f}\, S_1 + (f - 1)/r_o}{r_o}\right] R\, R_o^{\,T} - \dot{f}\, S_2\, R\, \dot{R}_o^{\,T} + \frac{(f - 1)\, S_1}{r_o}\, \dot{R}\, R_o^{\,T}$$

$$+ (f - 1)\, S_2\, \dot{R}\, \dot{R}_o^{\,T} + U\, \dot{R}\, \ddot{R}_o^{\,T} + f\, I$$

$$\text{PHI\_MC}_{1\text{ to }3,\ 4\text{ to }6} = \frac{\partial R}{\partial \dot{R}_o} = - \dot{f}\, S_2\, R\, R_o^{\,T} - (\dot{g} - 1)\, S_2\, R\, \dot{R}_o^{\,T} + (f - 1)\, S_2\, \dot{R}\, R_o^{\,T}$$

$$+ g\, S_2\, \dot{R}\, \dot{R}_o^{\,T} + g\, I - U\, \dot{R}\, \dot{R}_o^{\,T}$$

$$\text{PHI\_MC}_{4\text{ to }6,\ 1\text{ to }3} = \frac{\partial \dot{R}}{\partial R_o} = - \dot{f}\left(\frac{S_0}{r\, r_o} + \frac{1}{r^2} + \frac{1}{r_o^{\,2}}\right) R\, R_o^{\,T} - \left[\frac{\dot{f}\, S_1 + (\dot{g} - 1)/r}{r}\right] R\, \dot{R}_o^{\,T}$$

$$+ \left[\frac{\dot{f}\, S_1 + (f - 1)/r_o}{r_o}\right] \dot{R}\, R_o^{\,T} + \dot{f}\, S_2\, \dot{R}\, \dot{R}_o^{\,T} + \dot{f}\, I + U\, \ddot{R}\, \ddot{R}_o^{\,T}$$

$$\text{PHI\_MC}_{4\text{ to }6,\ 4\text{ to }6} = \frac{\partial \dot{R}}{\partial \dot{R}_o} = - \left[\frac{\dot{f}\, S_1 + (\ddot{g} - 1)/r}{r}\right] R\, R_o^{\,T} - \frac{(\dot{g} - 1)\, S_1}{r}\, R\, \dot{R}_o^{\,T} + \dot{f}\, S_2\, \dot{R}\, R_o^{\,T}$$

$$+ (\dot{g} - 1)\, S_2\, \dot{R}\, \dot{R}_o^{\,T} + \dot{g}\, I - U\, \ddot{R}\, \dot{R}_o^{\,T}$$

FIGURE 4.2.8-1 Position - Velocity Portion of State Transition Matrix.

4.2.9 Covariance Matrix Initialization

In circumstances in which the orbiter or target position and velocity elements of the onboard filter covariance matrix are to be initialized to UVW values, the following steps shall be performed (in the order indicated):

1. data shall be input to this subfunction as described by the inlist below

   IN LIST: $\underline{SIG}$, $\underline{COR}$, $\underline{R}$, $\underline{V}$

   where $\underline{SIG}$ is a 6-element vector of standard deviations in the UVW coordinate system

   SIG_1, U - position

   SIG_2, V - position

   SIG_3, W - position

   SIG_4, U - velocity ($\dot{U}$)

   SIG_5, V - velocity ($\dot{V}$)

   SIG_6, W - velocity ($\dot{W}$)

   and where $\underline{COR}$ is a 7-element vector of correlation coefficients, also in the UVW coordinate system

   COR_1, correlation between U-V

   COR_2, correlation between U-$\dot{U}$

   COR_3, correlation between U-$\dot{V}$

   COR_4, correlation between V-$\dot{U}$

   COR_5, correlation between V-$\dot{V}$

   COR_6, correlation between W-$\dot{W}$

   COR_7, correlation between $\dot{U}$-$\dot{V}$

and where $\underline{R}$ and $\underline{V}$ are the current orbiter or target position and velocity vectors, respectively, in M50 coordinates.

2. the current 6X6 covariance matrix shall be zeroed

$$E\_TEMP = 0.$$

3. the diagonal elements of E_TEMP shall be computed

$$E\_TEMP_{I,I} = SIG_I \ SIG_I, \quad \text{for } I = 1,6$$

4. next, position and velocity submatrix elements as well as the upper right position-velocity covariance elements shall be computed

$$E\_TEMP_{1,2} = COR_1 \ SIG_1 \ SIG_2$$
$$E\_TEMP_{1,4} = COR_2 \ SIG_1 \ SIG_4$$
$$E\_TEMP_{1,5} = COR_3 \ SIG_1 \ SIG_5$$
$$E\_TEMP_{2,4} = COR_4 \ SIG_2 \ SIG_4$$
$$E\_TEMP_{2,5} = COR_5 \ SIG_2 \ SIG_5$$
$$E\_TEMP_{3,6} = COR_6 \ SIG_3 \ SIG_6$$
$$E\_TEMP_{4,5} = COR_7 \ SIG_4 \ SIG_5$$
$$E\_TEMP_{2,1} = E\_TEMP_{1,2}$$
$$E\_TEMP_{5,4} = E\_TEMP_{4,5}$$

5. and, finally, a transformation matrix from UVW to M50 coordinate systems is acquired at current time, and used to rotate the E_TEMP matrix into the M50 system. The lower left position-velocity covariance is also defined

$M = UVW\_TO\_M50\ (\underline{R}, \underline{V})$

$E\_TEMP_{1\ to\ 3,\ 1\ to\ 3} = M\ E\_TEMP_{1\ to\ 3,\ 1\ to\ 3}\ M^T$

$E\_TEMP_{4\ to\ 6,\ 4\ to\ 6} = M\ E\_TEMP_{4\ to\ 6,\ 4\ to\ 6}\ M^T$

$E\_TEMP_{1\ to\ 3,\ 4\ to\ 6} = M\ E\_TEMP_{1\ to\ 3,\ 4\ to\ 6}\ M^T$

$E\_TEMP_{4\ to\ 6,\ 1\ to\ 3} = (E\_TEMP_{1\ to\ 3,\ 4\ to\ 6})^T$

6. the 6X6 covariance matrix E_TEMP shall be output from this subfunction.

4.3 NAVIGATION PROCESSING PRINCIPAL FUNCTIONS

The two navigation processing principal functions applicable during operational sequence 2 (and contained in the orbit operations computer load) are:

1. On-Orbit Navigation, and
2. Rendezvous Navigation.

Both of these functions will be initialized and cyclically executed under control of the on-orbit/rendezvous navigation sequencer principal function. Detailed requirements for both of the navigation processing principal functions are discussed in the following subsections.

4.3.1 Onorbit Navigation

The onorbit navigation principal function shall provide an up-to-date estimate of the orbiter's position, velocity, and other parameters for software users such as guidance and displays. This principal function shall be scheduled by the onorbit/rendezvous navigation sequencer principal function.

The onorbit navigation principal function shall use selected IMU data and a model of the Earth's gravitational acceleration to maintain a current estimate of the orbiter's state vector during powered flight. During coasting flight, models of the Earth's gravitational acceleration, aerodynamic drag acceleration, venting acceleration, and uncoupled RCS thrusting acceleration shall be used to maintain a current estimate of the orbiter state vector. A single state vector shall consist of three position components, three velocity components, and three unmodeled acceleration bias states.

No external sensor data shall be processed; however a 9x9 dimensional matrix initialized by the onorbit/rendezvous sequencer principal function shall be propagated along with the orbiter's state vector.

A ground update capability shall enable automatic reinitialization of the orbiter's state vector and covariance matrix

during coasting flight. This capability shall also provide for storage of an uplinked target state vector (and covariance matrix for eventual initialization purposes by the rendezvous navigation principal function.

The onorbit navigation principal function is composed of four primary subfunctions:

1. A control subfunction, described in Section 4.3.1.1.
2. A state and covariance setup subfunction, described in section 4.3.1.2.
3. A state propagation subfunction, described in section 4.3.1.3.
4. A covariance propagation subfunction, described in section 4.3.1.4

Tables 4.3.1-1 and 4.3.1-2 are the Level B CPDS tables which show data flow between the onorbit navigation and other principal functions.

ORIGINAL PAGE IS
OF POOR QUALITY

TABLE 4.3.1-1 ONORBIT NAVIGATION PRINCIPAL FUNCTION INPUT LIST

LEVEL B MNEMON	LEVEL C FSSR VARIABLE NAME	EXTERNAL PRINCIPAL FUNCTION SOURCE	INTERNAL SUBFUNCTION DESTINATION (SUBFUNCTIONS WITHIN THIS PRINCIPAL FUNCTION WHICH UTILIZE THE VARIABLE)	
			SUBFUNCTION NAME	SUBFUNCTION INPUT TABLE
	PWRD_FLT_NAV	ORB/RND NAV SEQ	• covariance matrix propagation • state propagation	4.3.1.4-1 4.3.1.3-1
	REND_NAV_FLAG	ORB/RND NAV SEQ	• state and covariance setup • state propagation • covariance matrix propagation	4.3.1.2-1 4.3.1.3-1 4.3.1.4-1
TBD	OV_UPLINK	(ground uplink processor)	• state and covariance setup	4.3.1.2-1
	TV_UPLINK	(ground uplink processor)	• state and covariance setup	4.3.1.2-1
	R_GND V_GND T_GND R_TV_GND V_TV_GND T_TV_GND DO_AUTO_UPDATE	(ground uplink processor)	• state and covariance setup	4.3.1.2-1

TABLE 4.3.1-1 ONORBIT NAVIGATION PRINCIPAL FUNCTION INPUT LIST (cont'd)

LEVEL B MNEMON	LEVEL C FSSR VARIABLE NAME	EXTERNAL PRINCIPAL FUNCTION SOURCE	INTERNAL SUBFUNCTION DESTINATION (SUBFUNCTIONS WITHIN THIS PRINCIPAL FUNCTION WHICH UTILIZE THE VARIABLE)	
			SUBFUNCTION NAME	SUBFUNCTION INPUT TABLE
	TOT_ACC	ORB/RND NAV SEQ	• state propagation • covariance matrix propagation	4.3.1.3-1 4.3.1.4-1
	V_CURRENT_FILT	IMU RM	• state propagation	4.3.1.3-1
	T_CURRENT_FILT	IMU RM	• state and covariance matrix setup • state propagation	4.3.1.2-1 4.3.1.3-1
TBD	R_FILT V_FILT	ORB/RND NAV SEQ	• state propagation • covariance matrix propagation	4.3.1.3-1 4.3.1.4-1
	V_LAST_FILT T_LAST_FILT	ORB/RND NAV SEQ	• state propagation	4.3.1.3-1
	VENT_THRUST_BIAS SQR_EMU C_MN_AN S_MN_AN C_MX_AN S_MX_AN	ORB/RND NAV SEQ	• state propagation	4.3.1.3-1
	E	ORB/RND NAV SEQ	• covariance matrix propagation	4.3.1.4-1

TABLE 4.3.1-1 ONORBIT NAVIGATION PRINCIPAL FUNCTION INPUT LIST (cont'd)

LEVEL B MNEMON	LEVEL C FSSR VARIABLE NAME	EXTERNAL PRINCIPAL FUNCTION SOURCE	INTERNAL SUBFUNCTION DESTINATION (SUBFUNCTIONS WITHIN THIS PRINCIPAL FUNCTION WHICH UTILIZE THE VARIABLE)	
			SUBFUNCTION NAME	SUBFUNCTION INPUT TABLE
TBD	SIG_UPDATE COV_COR_UPDATE SIG_TV_UPDATE COV_COR_TV_UPDATE	(ground uplink processor)	• state and covariance setup	4.3.1.2-1

ORIGINAL PAGE IS OF POOR QUALITY

TABLE 4.3.1-2 ONORBIT NAVIGATION PRINCIPAL FUNCTION OUTPUT LIST

LEVEL B MNEMON	LEVEL C FSSR VARIABLE NAME	EXTERNAL PRINCIPAL FUNCTION SOURCE	INTERNAL SUBFUNCTION DESTINATION (SUBFUNCTIONS WITHIN THIS PRINCIPAL FUNCTION WHICH UTILIZE THE VARIABLE)	
			SUBFUNCTION NAME	SUBFUNCTION INPUT TABLE
	USE_IMU_DATA	ORB USER PARAM PROC	• state propagation	4.3.1.3-2
	R_RESET V_RESET T_RESET V_IMU_RESET FILT_UPDATE	ORB USER PARAM PROC	• onorbit control	4.3.1.1-2
TBD	R_TV V_TV T_TV TARG_VEC_AVAIL	ORB/RND NAV SEQ	• state and covariance setup	4.3.1.2-2
	DID_AUTO_UPDATE	(ground uplink processor)	• state and covariance setup	4.3.1.2-2

4.3.1.1 On-Orbit Control

The on-orbit navigation principal function will provide the capability to control the propagation and ground update of the state vector and the covariance matrix.

A. Detailed Requirements

On-orbit control will perform the following tasks in the order indicated (for definitions of variables, refer to Tables 4.3.1.1-1 and 4.3.1.1-2):

1. The on-orbit state propagation subfunction will propagate the state vector as described in Section 4.3.1.3.

2. The on-orbit covariance propagation subfunction will propagate the covariance matrix as described in Section 4.3.1.4.

3. The on-orbit state and covariance setup subfunction will perform automatic in-flight updates as required, as described in Section 4.3.1.2.

4. The position and velocity, the associated time tag, and the accumulated IMU velocity counts will be stored for use by the user parameter state propagator:

   $\underline{R}$_RESET = $\underline{R}$_FILT

   $\underline{V}$_RESET = $\underline{V}$_FILT

   T_RESET = T_LAST_FILT

Finally the filter update flag will be set to ON to indicate to users that the current navigation cycle is complets:

FILT_UPDATE = ON

B. Interface Requirements

The input and output parameters are listed in Tables 4.3.1.1-1 and 4.3.1.1-2.

C. Processing Requirements

On-orbit control will be executed while the on-orbit navigation principal function is scheduled.

D. Constraints

None.

E. Supplemental Information

A suggested implementation of on-orbit control is illustrated by NAV_ONORBIT in Appendix B

TABLE 4.3.2.1-1. On-Orbit Control Input Parameters

DESCRIPTION	SYMBOL	INPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	SAMPLE RATE
Filter current shuttle position vector in M50 coordinates	R_FILT	On-orbit state prop.	V	DP		Ft	Filter rate
Filter current shuttle velocity vector in M50 coordinates	V_FILT	On-orbit state prop.	V	DP		Ft/sec	Filter rate
Time of the filter state vector	T_LAST_FILT	On-orbit state prop.	F	DP		Sec	Filter rate
Previously read selected accumulated IMU velocity	V_LAST_FILT	On-orbit state prop.	V	DP		Ft/sec	Filter rate

TABLE 4.3.1.1-2. On-Orbit Control Output Parameters

DESCRIPTION	SYMBOL	OUTPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	COMPUTATION RATE
Vehicle position vector after all navigation update reserved for reset of guidance integrator position vector R_AVG_G	R_RESET	*	V	DP		Ft	Filter rate
Vehicle velocity vector after all navigation updates reserved for reset of guidance integrator velocity vector V_AVG_G	V_RESET	*	V	DP		Ft/sec	Filter rate
Time associated with reserved reset state	T_RESET	*	F	DP		Sec	Filter rate
Copy of V_CURRENT_FILT reserved as velocity count at start of extrapolation interval when guidance integrator is reset	V_IMU_RESET	*	V	DP		Ft/sec	Filter rate
Switch indicating (ON) that current measurement processing is complete	FILT_UPDATE	*	D		OFF ON		Filter rate

* Refer to on-orbit navigation principal function out list

4.3.1.2 State and Covariance Setup - This subfunction is required to set up the proper state vector and covariance matrix as a result of an automatic inflight update during operation of the onorbit navigation principal function. This subfunction shall be capable of performing the following basic tasks:

1. predict uplinked orbiter state vector (M50 coordinates) to current time from uplinked time tag,
2. initialize (6 x 6) orbiter position/velocity covariance matrix to pre-mission stored (or uplinked) UVW standard deviations and correlation coefficients; and initialize diagonal elements of the filter covariance matrix associated with unmodeled acceleration bias errors, to pre-mission stored values (in body coordinates),
3. store uplinked target position/velocity vector, time tag, and selected UVW standard deviations and correlation coefficients for future usage in rendezvous navigation initialization.

A. Detailed Requirements. Section 4.2.5 contains a description of the detailed requirements for this subfunction (the REND_NAV_FLAG will be in the OFF setting, thus indicating those requirements necessary during operation of the onorbit navigation principal function).

B. Interface Requirements. Input and output parameters are listed in the tables 4.3.1.2-1 and 4.3.1.2-2, respectively.

C. Processing Requirements. The state and covariance setup subfunction shall be performed each navigation cycle; however, the automatic inflight update task shall only be performed when a ground uplink has been received (i.e, the DO_AUTO_UPDATE flag has been set to On by the ground uplink processor).

D. Constraints. The following constraints apply to the state and covariance setup subfunction during operation of the onorbit navigation principal function.

1. Automatic inflight updates of either orbiter and/or target which data shall not be performed during powered flight arcs (i.e, only during coasting flight regions), since the onorbit precision state prediction algorithm assumes coasting flight conditions.
2. The state and covariance setup subfunction shall be capable of reacting to the uplink of orbiter and/or target vehicle data in the same navigation cycle.
3. The ground uplink processor shall reset the DO_AUTO_UPDATE flag to OFF prior to the next navigation cycle, to prevent multiple navigation re-initializations with the same uplinked data.

4. The capability shall be provided to uplink the following data in a single transmission:

- vehicle position (3 double precision words)
- vehicle velocity (3 double precision words)
- time tag (1 double precision word)
- vehicle identifier (1 bit)
- position/velocity error standard deviations (6 double precision words)
- position/velocity error correlation coefficients (7 double precision words)

All the data in a single transmission shall pertain to one vehicle, only (either orbiter or target), as indicated by the "vehicle identifier" bit, above.

5. The onboard software (ground uplink processor) receiving the data in item 4., above, shall perform the following functions upon receiving uplink data:

   - Test the vehicle identifier to determine if the data pertains to the orbiter or target,
   - Set up one of the following two variable sets depending on the results of the above test.

R_GND V_GND T_GND OV_UPLINK= ON SIG_UPDATE COV_COR_UPDATE	for orbiter vehicle data uplink

OR

R_TV_GND
V_TV_GND
T_TV_GND
TV_UPLINK= ON
SIG_TV_UPDATE
COV_COR_TV_UPDATE

for target vehicle data uplink

E. <u>Supplementary Information</u>. A suggested inplementation in the form of detailed flow charts, can be found in Appendix B and C under the following names:

ONORBIT_REND_AUTO_INFLIGHT_UPDATE
ONORBIT_REND_STATE_AND_COV_SETUP (CODE)
ONORBIT_COVINIT_UVW
ACCEL_PERT_ONORBIT

Appendix B

ONORBIT_PREDICT ~ Appendix C

TABLE 4.3.1.2-1 STATE AND COVARIANCE SETUP INPUT LIST

DESCRIPTION	SYMBOL	INPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	SAMPLE RATE
Flag indicating (ON) that an automatic inflight update of either orbiter and/or target state and covariance matrix is to be performed	DO_AUTO_UPDATE	*	D	-	ON/OFF	-	NAV rate
flag indicating whether rendezvous navigation active (ON), or onorbit navigation active (OFF)	REND_NAV_FLAG	*	D	-	ON/OFF	-	As rqd
flag set by ground uplink processor indicating (ON) that orbiter vehicle state vector has been uplinked	OV_UPLINK	*	D	-	ON/OFF	-	As rqd.
flag set by ground uplink processor indicating (ON) that target vehicle state vector has been uplinked	TV_UPLINK	*	D	-	ON/OFF	-	As rqd

* onorbit navigation principal function input list

TABLE 4.3.1.2-1. (Continued) STATE AND COVARIANCE SETUP INPUT LIST

DESCRIPTION	SYMBOL	INPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	SAMPLE RATE
flag indicating degree of gravitational potential model	GM_DEG	**	I	S	1-8	-	As rqd
flag indicating order of gravitational potential model	GM_ORD	**	I	S	0-8	-	As rqd
flag which activates (1) or deactivates (0) the drag acceleration model	DRAG_MODE_NAV	**	I	S	0,1	-	As rqd
flag which activates (1) or deactivates (0) the venting and RCS-uncoupled-thrusting model	VENT_MODE_NAV	**	I	S	0,1	-	As rqd
integration step-size for precision state prediction	PREC_STEP	**	I	S	-	sec	As rqd

** pre-mission load

TABLE 4.3.1.2-1 (Continued) STATE AND COVARIANCE SETUP INPUT LIST

DESCRIPTION	SYMBOL	INPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	SAMPLE RATE
uplinked orbiter position vector (M50)	R_GND	*	V	DP	-	ft	As rqd
uplinked orbiter velocity vector (M50)	V_GND	*	V	DP	-	ft/sec	As rqd
uplinked orbiter state vector time tag	T_GND	*	F	DP	-	sec	As rqd
time tag of current filter state vector	T_CURRENT_FILT	state propagation	F	DP	-	sec	As rqd
vector (6 x 1) of standard deviations (UVW) for orbiter position/velocity covariance initialization (ground update)	SIG_UPDATE	*, **	V	DP	-	vary	As rqd

* onorbit navigation principal function input list
** pre-mission load

TABLE 4.3.1.2-1 (Continued) STATE AND COVARIANCE SETUP INPUT LIST

DESCRIPTION	SYMBOL	INPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	SAMPLE RATE
vector (7 x 1) of correlation coefficients associated with UVW standard deviations SIG_UPDATE used for orbiter position/velocity covariance initialization (ground update)	COV_COR_UPDATE	*,**	V	DP	-1,1	-	As rqd
flag indicating (ON) that an automatic inflight update of either orbiter and/or target state and covariance matrix is to be performed.	DO_AUTO_UPDATE	*	D	-	ON/OFF	-	NAV rate
flag indicating whether rendezvous navigation active (ON), or onorbit navigation active (OFF)	REND_NAV_FLAG	*	D	-	ON/OFF	-	As rqd
flag set by ground uplink processor indicating (ON) that orbiter vehicle state vector has been uplinked	OV_UPLINK	*	D	-	ON/OFF	-	As rqd

* onorbit navigation principal function input list

** pre-mission load

ORIGINAL PAGE IS OF POOR QUALITY

TABLE 4.3.1.2-1 (Continued) STATE AND COVARIANCE SETUP INPUT LIST

DESCRIPTION	SYMBOL	INPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	SAMPLE RATE
flag set by ground uplink processor indicating (ON) that orbiter vehicle state vector has been uplinked	TV_UPLINK	*	D	-	ON/OFF	-	As rqd
flag indicating degree of gravitational potential model	GM_DEG	**	I	S	1-8	-	As rqd
flag indicating order of gravitational potential model	GM_ORD	**	I	S	0-8	-	As rqd
flag which activates (1) or deactivates (0) the drag acceleration model	DRAG_MODE_NAV	**	I	S	0,1	-	As rqd
flag which activates (1) or deactivates (0) the venting and RCS-uncoupled-thrusting model	VENT_MODE_NAV	*	D	-	ON/OFF	-	NAV rate
integration step-size for precision state prediction	PREC_STEP	**	I	S	-	sec	As rqd

* onorbit navigation principal function input list
** pre-mission load

TABLE 4.3.1.2-1 (continued) STATE AND COVARIANCE SETUP INPUT LIST

DESCRIPTION	SYMBOL	INPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	SAMPLE RATE
uplinked orbiter position vector (M50)	R_GND	*	V	DP	-	ft	As rqd
uplinked orbiter velocity vector (M50)	V_GND	*	V	DP	-	ft/sec	As rqd
uplinked orbiter state vector time tag	T_GND	*	F	DP	-	sec	As rqd
time tag of current filter state vector	T_CURRENT_FILT	state propagation	F	DP	-	sec	As rqd
vector (6 x 1) of standard deviations (UVW) for orbiter position/velocity covariance initialization (ground update)	SIG_UPDATE	*,**	V	DP	-	vary	As rqd

* onorbit navigation principal function input list
** pre-mission load

TABLE 4.3.1.2-1 (Continued) STATE AND COVARIANCE SETUP INPUT LIST

DESCRIPTION	SYMBOL	INPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	SAMPLE RATE
vector (7 x 1) of correlation coefficients associated with UVW standard deviations SIG_UPDATE used for orbiter position/velocity covariance initialization (ground update)	COV_COR_UPDATE	*, **	V	DP	-1,1	-	As rqd
earth gravitational constant	EARTH_MU	**	F	DP	-	$\frac{ft^3}{sec^2}$	As rqd
vector (3 x 1) of unmodeled acceleration bias error variances (body coordinate system)	COV_ACCEL_BODY_INIT	**	V	DP	-	$\frac{ft^2}{sec^4}$	As rqd
uplinked target vehicle position vector (M50)	R_TV_GND	*	V	DP	-	ft	As rqd
uplinked target vehicle velocity vector (M50)	V_TV_GND	*	V	DP	-	ft/sec	As rqd

* onorbit navigation principal function input list
** pre-mission load

TABLE 4.3.1.2-1 (Continued) STATE AND COVARIANCE SETUP INPUT LIST

DESCRIPTION	SYMBOL	INPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	SAMPLE RATE
uplinked time tag of target vehicle state vector	T_TV_GND	*	F	DP	-	sec	As rqd
vector (6 x 1) of standard deviations (UVW) for target vehicle position/velocity covariance initialization (ground update)	SIG_TV_UPDATE	*,**	V	DP	-	vary	As rqd
vector (7 x 1) of correlation coefficients associated with UVW standard deviations SIG_TV_UPDATE used for target vehicle position/velocity covariance initialization (ground update)	COV_COR_TV_UPDATE	*,**	V	DP	-1,1	-	As rqd
(see section 4.8, I-Load Requirements)	(acceleration model and predictor constants)	**	-	-	-	-	As rqd

* onorbit navigation principal function input list

** pre-mission load

ORIGINAL PAGE IS OF POOR QUALITY

TABLE 4.3.1.2-2 STATE AND COVARIANCE SETUP OUTPUT LIST

DESCRIPTION	SYMBOL	OUTPUT DESTINATION	TYPE	PRECISION	RANGE	UNITS	COMPUTATION RATE
flag indicating (ON) that an automatic in-flight update has been performed	DID_AUTO_UPDATE	*	D	-	ON/OFF	-	NAV rate
orbiter position vector (M50)	R_FILT	state propagation, covariance propagation, onorbit control	V	DP	-	ft	As rqd
orbiter velocity vector (M50)	V_FILT	state propagation, covariance propagation onorbit control	V	DP	-	ft/sec	As rqd
vector of orbiter total acceleration (M50)	TOT_ACC	state propagation, covariance propagation	V	DP	-	ft/sec^2	As rqd
vector (3 x 1) of unmodeled acceleration bias errors (body coord. system)	VENT_THRUST_BIAS	state propagation	V	DP	-	ft/sec^2	As rqd

* onorbit navigation principal function output list

TABLE 4.3.1.2-2 (Continued) STATE AND COVARIANCE SETUP OUTPUT LIST

DESCRIPTION	SYMBOL	OUTPUT DESTINATION	TYPE	PRECISION	RANGE	UNITS	COMPUTATION RATE
filter covariance matrix of orbiter position, velocity, and unmodeled acceleration bias errors (9 x 9 dimensional)	E	covariance propagation	M	DP	-	vary	As rqd
target vehicle position vector (M50)	R_TV	*	V	DP	-	ft	As rqd
target vehicle velocity vector (M50)	V_TV	*	V	DP	-	ft/sec	As rqd
time tag of target vehicle state vector	T_TV	*	F	DP	-	sec	As rqd
flag indicating (ON) the availability of a target vehicle state vector and time tag for re-initialization purposes.	TARG_VEC_AVAIL	*	D	-	ON/OFF	-	As rqd

* onorbit navigation principal function output list

4.3.1.3 State Propagation

This subfunction will perform a number of tasks related to the propagation of the orbiter state vector.

The task of reading (snapping) the IMU shall be performed to obtain the current time and the accumulated sensed velocity. Details of the IMU snap task are to be found in Section 4.2.1.1.

Available acceleration models include gravitational accelerations (always used) and non-gravitational accelerations (drag, venting and uncoupled RCS thrusting). The latter shall be used in those circumstances in which sensed accelerations obtained from the IMU accumulated sensed velocities are judged to be insignificant. These acceleration models are described in detail in Section 4.2.1.2.

The equations of motion will be integrated with either a super-g algorithm (see section 4.2.1.3.1) intended primarily for powered flight phases (i.e., those phases in which significant non-gravitational accelerations are sensed) or a precision propagation algorithm designed specifically for coasting flight phases and described in detail in section 4.2.1.3.2.

The task of propagation of biases shall be performed by multiplying the previous value of each bias by unity. The three biases propagated in this way represent unmodeled accelerations in body coordinates.

A. Detailed Requirements

The computations that shall be carried out for advancement of the position and velocity vectors are the following:

1. The IMU shall be snapped (see section 4.2.1.1 for details of this task).

2. Values of the position and velocity vectors calculated in the previous navigation cycle, together with the total acceleration, shall be saved for use in the current cycle:

   $\underline{T}OT\_ACC\_LAST = \underline{T}OT\_ACC$

   $\underline{R}\_LAST = \underline{R}\_FILT$

   $\underline{V}\_LAST = \underline{V}\_FILT$

3. The time interval for advancement shall be calculated by subtracting the time tag of the previous cycle from the time obtained from the IMU snap:

   DT_FILT = T_CURRENT_FILT-T_LAST_FILT

4. The flag that indicates the choice of integrator shall then be checked. This flag, PWRD_FLT_NAV, is set by the onorbit/rendezvous sequencer principal function. It is set to OFF when in a coasting flight phase and set to ON just before a burn.

4.1 If the flag is found to be ON, the Super-g integrator shall be invoked. This requires the setting of certain flags. It also requires comparing the acceleration calculated from the IMU sensed velocities with a pre-

stored threshold value below which this acceleration shall be ignored.

So, the following steps are needed:

4.1.1 Find the difference in the accumulated sensed velocity

$$\underline{DV}\_FILT = \underline{V}\_CURRENT\_FILT-\underline{V}\_LAST\_FILT$$

4.1.2 Calculate on acceleration magnitude from $\underline{DV}$_FILT and DT_FILT and compare it with the threshold value:

$$\frac{|\underline{DV}\_FILT|}{DT\_FILT} > DA\_THRESHOLD$$

Then, if the calculated acceleration is larger than the threshold value, set the following flags:

USE_IMU_DATA = ON

IGD = GM_DEG_LOW

IGO = GM_ORD_LOW

IDRAG = 0

IVENT = 0

and set

$$\underline{DV} = \underline{DV}\_FILT$$

On the other hand, if the calculated absolute value of the acceleration is below the threshold level, set

USE_IMU_DATA = OFF

IGD = GM_DEG

IGO = GM_ORD

IDRAG = 1

IVENT = 1

and

$\underline{DV}$ = 0.

4.1.3 Find a value of the sensed acceleration based on $\underline{DV}$ (it could, therefore, be 0., thus ignoring the IMU readings)

$\underline{A}$_SENS=$\underline{DV}$/DT_FILT

4.1.4 Call the Super-g integrator with the flag values just set:

CALL: ONORBIT_SUPER_G

IN LIST: IGD, IGO, IDRAG, IVENT, 0, $\underline{R}$_FILT, $\underline{V}$_FILT, T_CURRENT_FILT, DT_FILT, $\underline{DV}$

OUT LIST: $\underline{R}$_FILT, $\underline{V}$_FILT, $\underline{G}$_NEW

4.2 In the situation where the PWRD_FLT_NAV is found to be OFF, the precision propagation integration scheme shall be called. The sequence, in this case, is as follows:

4.2.1 Check the REND_NAV_FLAG, and choose the step-size for the precision propagator according to the values of this flag. The step-size

does affect the accuracy of the integration, and it is natural that the accuracy requirements during the rendezvous phases be different from those in other phases of the orbital operations. The REND_NAV_FLAG, during the periods in which the Onorbit Navigation principal function is in operation, shall always be found to be OFF. This will result in setting

DT = PREC._STEP.

4.2.2 The vector A_SENS is required for the computation of TOT_ACC in a later step. The precision propagator being a coasting flight integrator, the sensed accelerations are not needed by it. Therefore, set

A_SENS=0.

4.2.3 Invoke the precision propagator with calling arguments that will cause the modeling of drag, venting and uncoupled thrusting accelerations, with the use of current attitude information.

CALL: ONORBIT_PRECISE_PROP

IN LIST: GM_DEG, GM_ORD, 1,1, 0, DT, R_FILT, V_FILT, T_LAST_FILT, T_CURRENT_FILT

OUTLIST: R_FILT, V_FILT, G_NEW

At the end of either step 4.1.4 or step 4.2.3, the values of R_FILT and V_FILT output by the corresponding integrator are the required propagated position and velocity vectors of the orbiter. The vector G_NEW is a modeled acceleration vector obtained according to the specified flag settings and and corresponding to R_FILT, V_FILT and T_CURRENT_FILT.

5. The REND_NAV_FLAG shall then be tested. This flag indicates whether or not it is necessary to also propagate the state of the target vehicle. While the onorbit navigation principal function is operative, this flag will always have the value OFF, and propagation of the target state vector will not be required.

6. Save the IMU readings for the next cycle and find the total acceleration vector for the orbiter (required for transition matrix calculations).

   T_LAST_FILT = T_CURRENT_FILT

   V_LAST_FILT = V_CURRENT_FILT

   TOT_ACC = G_NEW + A_SENS

B. Interface Requirements

Input and output parameters are to be found in tables 4.3.1.3-1 and 4.3.1.3-2 respectively.

C. Processing Requirements

None.

D. Constraints

The acceleration models task is needed not only by the navigation state propagation subfunction but also by the onorbit precision state prediction principal function and by the user parameter state propagation subfunction. Each of these users of the acceleration models shall set its own flags and therefore require a different calculation. To protect against interference in the acceleration computations, it is important that these computations not be interrupted.

E. Supplementary Information

A suggested implementation of this subfunction, in the form of a detailed flow diagram, may be found in Appendix B

ONORBIT_SUPER_G

ONORBIT_PRECISE_PROP

ONORBIT_NAV (IMU Snap Portion)

ONORBIT_REND_BIAS_AND_COV_PROP (CODE)

Table 4.3.1.3-1. On-Orbit State Propagation Input Parameters

DESCRIPTION	SYMBOL	INPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	SAMPLE RATE
Copy of V_IMU_CURRENT raw velocity counts reserved for measurement processing	V_CURRENT_FILT	*	V	DP		Ft/sec	Filter rate
MTU or clock time when IMU was read	T_CURRENT_FILT	*	F	DP		Sec	Filter rate
Flag indicating choice of integrator.	PWRD_FLT_NAV	*	D	[illegible]	ON,OFF	-	As needed
Filter current position vector in M50 coordinates	R_FILT	*, onorbit state and cov. setup.	V	DP		Ft	Filter rate
Total acceleration (sensed plus modeled)	TOT_ACC	*	V	DP		Ft/sec^2	Filter rate
Flag indicating if the current NAV phase is a rendezvous phase	REND_NAV_FLAG	*	D	--	ON,OFF	-	As needed
Orbiter velocity vector	V_FILT	*, onorbit state and cov. setup.	V	DP		Ft/sec	Filter rate
Angle of attack	ALPHA	*	F	DP	0-2Π	Rad	Filter rate
Angle of sideship	BETA	*	F	DP	0-2Π	Rad	
Acceleration model related constants	***	**					Filter rate

* Onorbit Navigation Principal Function Input List

** Premission loaded

*** These constants are listed and their values given in Section 4.8 (I-load requirements)

Table 4.3.1.3-2. On-Orbit State Propagation Output Parameters

DESCRIPTION	SYMBOL	OUTPUT DESTINATION	TYPE	PRECISION	RANGE	UNITS	SAMPLE RATE
Current position vector of orbiter in M50 coordinates	R_FILT	*,**	V	DP		Ft	Filter rate
Previous position vector of orbiter	R_LAST	**	V	DP		Ft	Filter rate
Total acceleration (sensed plus modeled) of orbiter	TOT_ACC	**	V	DP		Ft/sec^2	Filter rate
Previous total acceleration of orbiter	TOT_ACC_LAST	**	V	DP		Ft/sec^2	Filter rate
Orbiter velocity vector	V_FILT	*,**	V	DP		Ft/sec	Filter rate
Previous velocity vector of orbiter	V_LAST	**	V	DP		Ft/sec	Filter rate
Difference between two consecutive accumulated velocities snapped from IMU	DV_FILT	**	V	DP		Ft/sec	Filter rate
Copy of the current time tag, saved for next nav. cycle	T_LAST_FILT	Onorbit Nav.	F	DP		Sec	Filter rate
Time of the orbiter state vector	T_CURRENT_FILT	**	F	DP		Sec.	Filter rate
Difference between two consecutive times snapped from IMU	DT_FILT	**	F	DP		Sec	Filter rate
Previous IMU accumulated sensed velocity	V_LAST_FILT	Onorbit Nav.	V	DP		Ft/sec	Filter rate

Table 4.3.1.3-2. On-Orbit State Propagation Output Parameters

DESCRIPTION	SYMBOL	OUTPUT DESTINATION	TYPE	PRECISION	RANGE	UNITS	SAMPLE RATE
Flag indicating IMU accelerations are above threshold level	USE_IMU_DATA	*	D	-	ON-OFF	-	As needed

* Onorbit Navigation Principal Function Output List.

** Onorbit Covariance Propagation Subfunction.

4.3.1.4 Covariance Matrix Propagation

The covariance matrix propagation subfunction propagates the covariance matrix forward in time. The covariance matrix is propagated by utilizing the state transition matrix. Additive process noise is incorporated to account for unmodeled state and dynamic errors.

A. Detailed Requirements. A 9 by 9 covariance matrix shall be propagated with the navigation principal function. This covariance matrix defines the uncertainty in the state vector, which consists of position and velocity of the orbiter and unmodeled accelerations. The method of propagation is described in Section 4.2.2.

B. Interface Requirements. The input and output data are shown in Tables 4.3.1.4-1 and 4.3.1.4-2.

C. Processing Requirements. This subfunction will be called after the IMU sensor data have been read and after the state propagation subfunction has been executed.

D. Constraints. Prestored data are to be used for initialization. The propagated covariance matrix must remain symmetric.

E. Supplementary Information. A possible implementation of this subfunction is shown in the flow charts ONORBIT_REND_BIAS_AND_COV_PROP (CODE), PWRD_FLT_COV_PROP(CODE), MEAN_CONIC_PARTIAL_TRANSITION_MATRIX_6X6 and F_AND_G in Appendix B.

Table 4.3.1.4-1 - Onorbit Covariance Propagation Input Parameters

DESCRIPTION	SYMBOL	INPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	SAMPLE RATE
Interval over which to propagate the covariance matrix	DT_FILT	state propagation	F	DP		sec	filter rate
Correlation time constants for body venting	TAU_VENT	premission constant	V	DP		sec	filter rate
Variance of body venting variable	VAR_VENT_DT	premission load	V	DP		$\frac{(ft/sec^2)^2}{sec}$	filter rate
Structural body to M50 coordinate transformation matrix	M_SBODYM50	*	M	DP			filter rate
Drag acceleration coefficient percent error	D_COE_PCT_ERR	premission load	F	DP			filter rate
Drag acceleration vector	D	state	V	DP		ft/sec	filter rate
Flag indicating (ON) whether the rendezvous principal function is scheduled	REND_NAV_FLAG	*	D		ON,OFF		filter rate

* Onorbit principal function inlist

Table 4.3.1.4-1. (continued) - Onorbit Covariance Propagation Input Parameters

DESCRIPTION	SYMBOL	INPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	SAMPLE RATE
Filter current shuttle position vector in M50 coordinates	R_FILT	state propagation	V	DP		ft	filter rate
Filter current shuttle velocity vector in M50 coordinates	V_FILT	state propagation	V	DP		ft/sec	filter rate
Gravity acceleration at end of shuttle state integration interval	TOT_ACC	state propagation	V	DP		ft/sec^2	filter rate
Filter covariance matrix	E	measurement incorporation	M	DP		vary	filter rate
Flag indicating (ON) the desire to inhibit the processing of external measurement data by the navigation filter	MANEUVER_ON_FLAG	*	D		ON,OFF		filter rate

* Onorbit principal function inlist.

Table 4.3.1.4-1. (continued) - Onorbit Covariance Propagation Input Parameters

DESCRIPTION	SYMBOL	INPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	SAMPLE RATE
Gravitational constant of the earth	EARTH_MU	premission load	F	DP		$(ft^3/sec)^2$	filter rate
Square root of EARTH_MU	SQR_EMU	premission load	F	DP		ft^3/sec	filter rate
Identity matrix (3 x 3)	ID_MATRIX_3x3	premission load	M	DP			filter rate
Tolerance for succesive iterations in the solution of Kepler's equation	EPS_KEP	premission load	F	DP		rad	filter rate
Position vector of shuttle at the end of the last filter cycle	R_LAST	state propagation	V	DP		ft	filter rate
Velocity vector of shuttle at the end of the last filter cycle	V_LAST	state propagation	V	DP		ft/sec	filter rate
Gravity acceleration at start of shuttle state integration interval	TOT_ACC_LAST	state propagation	V	DP		ft/sec^2	filter rate

Table 4.3.1.4-1.(continued) - Onorbit Covariance Propagation Input Parameters

DESCRIPTION	SYMBOL	INPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	SAMPLE RATE
Difference between accumulated sensed IMU readings on present cycle and previous cycle	DV_FILT	state propagation	F	DP		ft/sec	filter rate
Variance for platform misalignment added as process noise in the covariance	VAR_IMU_ALIGN	premission load	V	DP		rad^2	filter rate
Time tag of the current filter state vector	T_LAST_FILT	state propagation	F	DP		sec	filter rate
Time of the last IMU alignment	T_ALIGN	premission load	F	DP		sec	filter rate
Variance of the platform drift	VAR_IMU_DRIFT	premission load	V	DP		rad^2	filter rate
Accelerometer quantization error variance	VAR_ACC_QUANT	premission load	F	DP		ft^2/sec^2	filter rate
Variance of unmodeled acceleration times scale time	VAR_UNMOD_ACC_DT	premission load	F	DP		ft^2/sec^3	filter rate

Table 4.3.2.1-2. - Onorbit Covariance Propagation Output Parameters

DESCRIPTION	SYMBOL	INPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	SAMPLE RATE
Filter covariance matrix	E	measurement incorporation	M	DP		vary	filter rate

4.3.2 Rendezvous Navigation

The rendezvous navigation principal function shall provide an up-to-date estimate of the orbiter and target position, velocity, and other parameters for software users such as guidance and displays. This principal function shall be scheduled by the onorbit/rendezvous navigation sequencer principal function.

The rendezvous navigation principal function shall use selected IMU data and a model of the Earth's gravitational acceleration to maintain a current estimate of the orbiter's state vector during powered flight. During coasting flight, models of the Earth's gravitational acceleration, aerodynamic drag acceleration, venting acceleration, and uncoupled RCS thrusting acceleration shall be used to maintain a current estimate of the orbiter and target state vectors. A single-string state vector configuration shall apply in coasting, powered flight, and TPF stationkeeping navigation as follows (19 elements):

- orbiter position (M1950) - 3 components
- orbiter velocity (M1950) - 3 components
- orbiter unmodeled acceleration biases (body axes) - 3 components
- target position (M1950) - 3 components
- target velocity (M1950) - 3 components
- sensor systematic biases (sensor axes) - 4 components

External sensor data shall be processed during coasting and TPF stationkeeping navigation phases. The following measurements shall be available:

rendezvous radar (range, range-rate, shaft angle, trunion angle)

star tracker (horizontal angle, vertical angle)

COAS (horizontal angle, vertical angle)

A 19x19 dimensional covariance matrix, initialized by the onorbit/rendezvous navigation sequencer principal function, shall be propagated along with the 19 element state vector, during all rendezvous navigation phases (coast, flight, TPF stationkeeping).

A ground update capability shall enable automatic re-initialization of the orbiter and/or target state vector (and other related non-position/velocity states) and covariance matrix during coasting and TPF stationkeeping navigation phases.

The rendezvous navigation principal function composed of eight primary subfunctions:

1. A control subfunction (section 4.3.2.1),
2. An external sensor data snap subfunction (section 4.3.2.2),
3. A sensor measurement selection subfunction (section 4.3.2.3),
4. A state and covariance setup subfunction (section 4.3.2.4),
5. A state propagation subfunction (section 4.3.2.5),

C.3

6. A covariance matrix propagation subfunction (section 4.3.2.6),
7. A state and covariance measurement incorporation subfunction (section 4.3.2.7), and
8. A measurement processing statistics subfunction (section 4.3.2.8).

Tables 4.3.2-1 and 4.3.2-2 are the level B CPDS tables which show data flow between the rendezvous navigation and other principal functions.

TABLE 4.3.2-1 RENDEZVOUS NAVIGATION PRINCIPAL FUNCTION INPUT LIST

LEVEL B MNEMON	LEVEL C FSSR VARIABLE NAME	EXTERNAL PRINCIPAL FUNCTION SOURCE	INTERNAL SUBFUNCTION DESTINATION (SUBFUNCTIONS WITHIN THIS PRINCIPAL FUNCTION WHICH UTILIZE THE VARIABLE)	
			SUBFUNCTION NAME	SUBFUNCTION INPUT TABLE
TBD	PWRD_FLT_NAV	ORB/RND NAV SEQ	• covariance matrix propagation • state propagation	4.3.2.6-1 4.3.2.5-1
	REND_NAV_FLAG	ORB/RND NAV SEQ	• state and covariance setup • state propagation • covariance matrix propagation	4.3.2.4-1 4.3.2.5-1 4.3.2.6-1
	OV_UPLINK	(ground uplink processor)	• state and covariance setup	4.3.2.4-1
	TV_UPLINK	(ground uplink processor)	• state and covariance setup	4.3.2.4-1
	R_GND V_GND T_GND R_TV_GND V_TV_GND DO_AUTO_UPDATE	(ground uplink processor)	• state and covariance setup	4.3.2.4-1
	TOT_ACC	ORB/RND NAV SEQ	• state propagation • covariance matrix propagation • state and covariance meas. incorp.	4.3.2.5-1 4.3.2.6-1 4.3.2.7-1

TABLE 4.3.2-1 RENDEZVOUS NAVIGATION PRINCIPAL FUNCTION INPUT LIST (cont'd)

LEVEL B MNEMON	LEVEL C FSSR VARIABLE NAME	EXTERNAL PRINCIPAL FUNCTION SOURCE	INTERNAL SUBFUNCTION DESTINATION (SUBFUNCTIONS WITHIN THIS PRINCIPAL FUNCTION WHICH UTILIZE THE VARIABLE)	
			SUBFUNCTION NAME	SUBFUNCTION INPUT TABLE
TBD	V_CURRENT_FILT	IMU RM	• state propagation	4.3.2.5-1
	T_CURRENT_FILT	IMU RM	• state and covariance matrix setup • state propagation • state and covariance meas. incorp.	4.3.2.4-1 4.3.2.5-1 4.3.2.7-1
	R_FILT V_FILT	ORB/RND NAV SEQ	• state propagation • covariance matrix propagation • state and covariance meas. incorp.	4.3.2.5-1 4.3.2.6-1 4.3.2.7-1
	V_LAST_FILT T_LAST_FILT	ORB/RND NAV SEQ	• state propagtion	4.3.2.5-1
	SQR_EMU C_MN_AN S_MN_AN C_MX_AN S_MX_AN	ORB/RND NAV SEQ	• state propagation	4.3.2.5-1
	E	ORB/RND NAV SEQ	• covariance matrix propagation	4.3.2.6-1
	USE_MEAS_DATA	ORB/RND NAV SEQ	• sensor measurement selection	4.3.2.3-1

TABLE 4.3.2-1 RENDEZVOUS NAVIGATION PRINCIPAL FUNCTION INPUT LIST (cont'd)

LEVEL B MNEMON	LEVEL C FSSR VARIABLE NAME	EXTERNAL PRINCIPAL FUNCTION SOURCE	INTERNAL SUBFUNCTION DESTINATION (SUBFUNCTIONS WITHIN THIS PRINCIPAL FUNCTION WHICH UTILIZE THE VARIABLE)	
			SUBFUNCTION NAME	SUBFUNCTION INPUT TABLE
TBD	N_ACCEPT N_REJECT SEQ_ACCEPT SEQ_REJECT	ORB/RND NAV SEQ	• measurement processing statistics	4.3.2.8-1
	R_TV V_TV G_TV	ORB/RND NAV SEQ	• state propagation • covariance matrix propagation • state and covariance meas. incorp.	4.3.2.5-1 4.3.2.6-1 4.3.2.7-1
	VENT_THRUST_BIAS	ORB/RND NAV SEQ	• state propagation • state and covariance meas. incorp.	4.3.2.5-1 4.3.2.7-1
	Q_RR_SHFT Q_RR_TURN Q_RR_RNG Q_RR_RNG_DOT RNG_DATA_GOOD RDOT_DATA_GOOD RR_ANGLE_DATA_GOOD M_M50_TO_BODY_RR T_REND_RADAR	REND RADAR SOP	• external sensor data snap • state and covariance meas. incorp.	4.3.2.2-1 4.3.2.7-1

TABLE 4.3.2-1 RENDEZVOUS NAVIGATION PRINCIPAL FUNCTION INPUT LIST (cont'd)

LEVEL B MNEMON	LEVEL C FSSR VARIABLE NAME	EXTERNAL PRINCIPAL FUNCTION SOURCE	INTERNAL SUBFUNCTION DESTINATION (SUBFUNCTIONS WITHIN THIS PRINCIPAL FUNCTION WHICH UTILIZE THE VARIABLE)	
			SUBFUNCTION NAME	SUBFUNCTION INPUT TABLE
TBD	Q_ST_HORIZ Q_ST_VERT N_ST_IN_USE ST_DATA_GOOD M_M50_TO_BODY_ST T_STAR_TRACKER Q_COAS_HORIZ Q_COAS_VERT N_COAS_IN_USE COAS_DATA_GOOD M_M50_TO_BODY_COAS T_COAS	STAR TRACKER SOP	• external sensor data snap • state and covariance meas. incorp.	4.3.2.2-1 4.3.2.7-1
	RR_ANGLES_ENABLE ST_ENABLE COAS_ENABLE RNG_AIF RDOT_AIR ANGLES_AIF	NAV MONITOR KIP	• sensor measurement selection	4.3.2.3-1
	SIG_UPDATE COV_COR_UPDATE SIG_TV_UPDATE COV_COR_TV_UPDATE	(ground uplink processor)	• state and covariance setup	4.3.2.4-1

TABLE 4.3.2-2 RENDEZVOUS NAVIGATION PRINCIPAL FUNCTION OUTPUT LIST

LEVEL B MNEMON	LEVEL C FSSR VARIABLE NAME	EXTERNAL PRINCIPAL FUNCTION SOURCE	INTERNAL SUBFUNCTION DESTINATION (SUBFUNCTIONS WITHIN THIS PRINCIPAL FUNCTION WHICH UTILIZE THE VARIABLE)	
			SUBFUNCTION NAME	SUBFUNCTION INPUT TABLE
TBD	USE_IMU_DATA	ORB USER PARAM PROC	• state propagation	4.3.2.5-2
	R_RESET V_RESET T_RESET V_TV_RESET R_TV_RESET V_TV_RESET FILT_UPDATE	ORB USER PARAM PROC	• rendezvous control	4.3.2.1-2
	DID_AUTO_UPDATE	(ground uplink processor)	• state and covariance setup	4.3.2.4-2
	TARG_VEC_AVAIL	ORB/RND NAV SEQ	• state and covariance setup	4.3.2.4-2

4.3.2.1 Rendezvous Control

The rendezvous navigation principle function shall provide the capability to control state and covariance matrix propagation and navigation filter updates.

A. Detailed requirements

Rendezvous control shall perform the following tasks in the order indicated. (For definitions of variables, see input and output tables 4.3.2.1-1 and 4.3.2.1-2.)

1. The accumulated IMU sensed velocity and the corresponding time tag shall be obtained as described in section 4.2.1.1.
2. An external sensor data snap shall be performed as described in section 4.3.2.2.
3. The state vector shall be propagated as described in section 4.3.2.5.
4. The covariance matrix as described in section 4.3.2.6.
5. The rendezvous sensor measurement selection subfunction shall determine which measurements are to be presented to the filter for processing, as described in section 4.3.2.3.
6. The state and covariance setup subfunction shall set up the proper state vector and covariance matrix for use by the state and covariance measurement incorporation task as described in section 4.3.2.4.

7. The state and covariance measurement incorporation subfunction shall update the state vector and covariance matrix for each of the measurements being processed as described in section 4.3.2.7. This subfunction is exercised for each measurement type only if data are to be processed as determined by the rendezvous sensor measurement selection subfunction. A counter (RR_ANGLE_MARK_NUM, RRDOT_MARK_NUM, ST_MARK_NUM, or COAS_MARK_NUM) shall be incremented for each measurement processed to indicate the mark number for post mission analysis purposes.

8. The position and velocity of the orbiter and the target, the associated time tag, and the accumulated velocity count shall then be stored for use by the user parameter state propagator,

R_RESET = R_FILT

V_RESET = V_FILT

T_RESET = T_LAST_FILT

R_TV_RESET = R_TV

V_TV_RESET = V_TV

V_IMU_RESET = V_LAST_FILT

Then the filter update flag shall be set to ON to indicate to users that the current rendezvous navigation filter update is complete.

FILT_UPDATE = ON

9. Finally, the measurement processing statistics subfunction shall be performed as described in section 4.3.2.8.

B. <u>Interface Requirements</u>.

The input and output parameters are listed in tables 4.3.2.1-1 and 4.3.2.1-2.

C. <u>Processing Requirements</u>

Rendezvous control shall be executed at a premission determined rate when the rendezvous navigation principle function is scheduled.

D. <u>Constraints</u>

None.

E. <u>Supplemental Information</u>

A suggested inplementation of rendezvous control is illustrated by NAV_RENDEZVOUS in Appendix B.

TABLE 4.3.2.1-1. - Rendzyous Control Input Parameters

DESCRIPTION	SYMBOL	INPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	SAMPLE RATE
Shuttle position vector in M50 coordinates	R_FILT	Rendezyous measurement incorporation	V	D		ft	Filter rate
Shuttle velocity vector in M50 coordinates	V_FILT	Rendzvous measurement incorporation	V	S		ft/sec	Filter rate
Time of latest filter update	T_LAST_FILT	Rendezvous state propagation	S	D		sec	Filter rate
Target position vector in M50 coordinates	R_TV	Rendezvous measurement incorporation	V	D		ft	Filter rate
Target velocity vector in M50 coordinates	V_TV	Rendezvous measurement incorporation	V	S		ft/sec	Filter rate
Last IMU velocity count	V_LAST_FILT	Rendezyous State propagation	V	S		ft/sec	Filter rate
Flag indicating that the rendezvous radar angles are to be processed	DO_RR_ANGLE_ NAV	Rendezvous sensor measurement selection	D				Filter rate
Flag indicating that the rendezvous radar range and range rate are to be processed.	DO_RRDOT_NAV	Rendezvous sensor measurement selection	D				Filter rate

TABLE 4.3.2.1-1. (continued) - Rendezvous Control Input Parameters

DESCRIPTION	SYMBOL	INPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	SAMPLE RATE
Flag indicating that star tracker angles are to be processed	DO_ST_ANGLE_NAV	Rendezvous sensor measurement selection	D				Filter rate
Flag indicating that COAS angles are to be processed	DO_COAS_ANGLE_NAV	Rendezvous sensor measurement selection	D				Filter rate

TABLE 4.3.2.1-2. - Rendezvous Control Output Parameters

DESCRIPTION	SYMBOL	OUTPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	COMPUTATION RATE
Counter indicating number of times rendezvous radar range and range rate were processed	RRDOT_MARK_NUM	Downlist	D	S			Filter rate
Counter indicating number of times rendezvous radar angles were processed	RR_ANGLE_MARK_NUM	Downlist	D	S			Filter rate
Counter indicating number of times startracker data were processed	ST_MARK_NUM	Downlist	D	S			Filter rate
Counter indicating number of times COAS data were processed	COAS_MARK_NUM	Downlist	D	S			Filter rate
Orbiter position vector after all navigation updates reserved for reset of guidance integrator position vector R_AVG_G	R_RESET	*	V	D		ft	Filter rate
Orbiter velocity vector after all navigation updates reserved for reset of guidance integrator velocity vector V_AVG_G	V_RESET	*	V	S		ft/sec	Filter rate

TABLE 4.3.2.1-2 (Continued) Rendezvous Control Output Parameters

DESCRIPTION	SYMBOL	OUTPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	COMPUTATION RATE
Time associated with reserved reset state	T_RESET	*	S	D		Sec	Filter rate
Target position vector after all navigation updates reserved for reset of guidance integrator position vector R_TARGET	R_TV_RESET	*	V	D		ft	Filter rate
Target velocity vector after all navigation updates reserved for reset of guidance integrator velocity vector V_TARGET	V_TV_RESET	*	V	S		ft/sec	Filter rate
Copy of V_LAST_FILT reserved as velocity count at start of extrapolation interval when guidance integrator is reset	V_IMU_RESET	*	V	D		ft/sec	Filter rate
Flag indicating (ON) that the current navigation cycle is complete	FILT_UPDATE	*	D				Filter rate

* Rendezvous navigation principal function output list

4.3.2.2 External Sensor Data Snap

The purpose of this subfunction during the rendezvous navigation phase is to collect and store sensor data from the Rendezvous Radar, the Star Tracker and the Crew Optical Alignment Sight (COAS).

The data sets used in navigation processing must be properly saved for use in the state and covariance measurement incorporation subfunction, whereas the actual data may continue to be refreshed by hardware sensor reading, sensor SOP processing, and selection filter unification.

A. <u>Detailed Requirements.</u>

During the rendezvous phases, data from the external sensors, together with the corresponding data good flags, associated time tags and rotation matrices from M50 to the orbiter body axes valid at those times, shall be obtained and stored. The equations are:

1. For the Rendezvous Radar.

SNAP REND_RADAR (Q_RR_SHFT, Q_RR_TRUN, Q_RR_RNG, Q_RR_RNG_DOT, RNG_DATA_GOOD, RDOT_DATA_GOOD, RR_ ANGLE_DATA_GOOD, M_M50_TO_BODY_RR, T_REND_RADAR)

where

Q_RR_SHFT is the shaft angle,

Q_RR_TRUN is the trunnion angle,

RR_ANGLE_DATA_GOOD the validity flag of the above measurements,

Q_RR_RNG is the radar range measurement,

RNG_DATA_GOOD the respective data good flag,

Q_RR_RNG_DOT the radar range rate reading,

RDOT_DATA_GOOD the respective validity indicator,

T_REND_RADAR the time at which these measurements are considered to have been effected, and

M_M50_TO_BODY_RR the transformation matrix from mean of 1950.0 coordinates to the body coordinate system at the time T_REND_RADAR.

2. For the Star Tracker,

SNAP STAR_TRACKER (Q_ST_HORIZ, Q_ST_VERT, N_ST_IN_USE, ST_DATA_GOOD, M_M50_BODY_ST, T_STAR_TRACKER)

where

Q_ST_HORIZ is the horizontal angle,

Q_ST_VERT the vertical angle,

ST_DATA_GOOD the data good flag relative to these angles,

N_ST_IN_USE the identifier of the particular star tracker that made the above measurements,

T_STAR_TRACKER the time tag, and

M_M50_BODY_ST the required rotation matrix at the time of the measurements.

3. For the COAS,

SNAP COAS (Q_COAS_HORIZ, Q_COAS_VERT, N_COAS_IN_USE, COAS_DATA_GOOD, M_M50_TO_BODY_COAS, T_COAS)

where

Q_COAS_HORIZ is the horizontal angle,

Q_COAS_VERT the vertical angle,

COAS_DATA_GOOD the flag that indicates the validity of the above readings,

N_COAS_IN_USE the identifier of the particular instrument used to obtain the angles,

T_COAS the time of the measurements, and

M_M50_TO_BODY_COAS the matrix that describes the rotation from the M50 to the body coordinate systems at the time T_COAS.

B. Interface Requirements

The input and output parameters are listed in Tables 4.3.2.2-1 and 4.3.2.2-2, respectively.

C. Processing Requirements.

It is required that the data from the sensors (measurements, ID's, validity flags, rotation matrices, and time tags) be made available for the collection and storage process. The collection rate (not necessarily sensor interrogations) is indicated by the onorbit/rendezvous navigation sequencer. However, this rate assumes that the available data are

fresh. This implies that SOP's processing and selection filtering must be at a rate equal to or greater than the collection rate.

D. Constraints.

The data collections should occur after a complete current set is available and just prior to use in navigation in order to supply current data.

E. Supplementary Information. A suggested implementation of the external sensor data snap subfunction in the form of a detailed flow chart, may be found in Appendix B as a portion of the NAV_RENDEZVOUS flow chart. The snap statement above implies the assignment of current values to the variable names shown in parenthesis.

TABLE 4.3.2.2-1 EXTERNAL SENSOR DATA SNAP INPUT PARAMETERS

DESCRIPTION	SYMBOL	INPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	SAMPLE RATE
Rendezvous radar shaft measurement	Q_RR_SHFT	*	F	DP		Rad	Filter rate
Rendezvous radar trunnion angle measurement	Q_RR_TRUN	*	F	DP		Rad	Filter rate
Rendezvous radar angle measurement data good flag	RR_ANGLE_DATA_GOOD	*	D	-	ON,OFF	-	Filter rate
Rendezvous radar range measurement	Q_RR_RNG	*	F	DP		Ft	Filter rate
Rendezvous radar range measurement data good flag	RNG_DATA_GOOD	*	D	-	ON,OFF	-	Filter rate
Rendezvous radar range rate measurement	Q_RR_RNG_DOT	*	F	DP		Ft/sec	Filter rate
Rendezvous radar range rate measurement data good flag	RDOT_DATA_GOOD	*	D	-	ON,OFF	-	Filter rate
Time of rendezvous radar measurements	T_REND_RADAR	*	F	DP		Sec	Filter rate
Rotation matrix, M50 to body, at T_REND_RADAR	M_M50_TO_BODY_RR	*	M	DP		Rad	Filter rate

* Rendezvous Navigation Principal Function Input List

TABLE 4.3.2.2-1 EXTERNAL SENSOR DATA SNAP INPUT PARAMETERS

DESCRIPTION	SYMBOL	INPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	SAMPLE RATE
Star tracker measured horizontal angle	Q_ST_HORIZ	*	F	DP		Rad	Filter rate
Star tracker measured vertical angle	Q_ST_VERT	*	F	DP		Rad	Filter rate
Star tracker measurement data good flag	ST_DATA_GOOD	*	D	-	ON,OFF	-	Filter rate
Star tracker identifier	N_ST_IN_USE	*	I	-	1,2	-	Filter rate
Time of star tracker measurements	T_STAR_TRACKER	*	F	DP		Sec	Filter rate
Rotation matrix, M50 to body, at T_STAR_TRACKER	M_M50_TO_BODY_ST	*	M	DP		-	Filter rate
COAS measured horizontal angle	Q_COAS_HORIZ	*	F	DP		Rad	Filter rate
COAS measured vertical angle	Q_COAS_VERT	*	F	DP		Rad	Filter rate
COAS measurement data good flag	COAS_DATA_GOOD	*	D	-	ON,OFF	-	Filter rate
COAS identifier	N_COAS_IN_USE	*	I	-	1,2	-	Filter rate

* Rendezvous Navigation Principal Function Input List

TABLE 4.3.2.2-1 EXTERNAL SENSOR DATA SNAP INPUT PARAMETERS (cont'd)

DESCRIPTION	SYMBOL	INPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	SAMPLE RATE
Time of COAS measurements	T_COAS	*	F	DP		Sec	Filter rate
Rotation matrix, M50 to body, at T_COAS	M_M50_TO_BODY_COAS	*	M	DP		-	Filter rate

* Rendezvous Navigation Principal Function Input List

TABLE 4.3.2.2-2 EXTERNAL SENSOR DATA SNAP OUTPUT PARAMETERS

DESCRIPTION	SYMBOL	OUTPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	COMPUTATION RATE
Rendezvous radar shaft angle measurement	Q_RR_SHFT	*	F	DP		Rad	Filter rate
Rendezvous radar trunnion angle measurement	Q_RR_TRUN	*	F	DP		Rad	Filter rate
Rendezvous radar angle measurements data good flag	RR_ANGLE_DATA_GOOD	*	D	-	ON,OFF	Ft	Filter rate
Rendezvous radar range measurement	Q_RR_RNG	*	F	DP		Ft	Filter rate
Rendezvous radar range measurement data good flag	RNG_DATA_GOOD	*	D	-	ON,OFF	-	Filter rate
Rendezvous radar range rate measurement	Q_RR_RNG_DOT	*	F	DP		Ft/sec	Filter rate
Rendezvous radar range rate measurement data good flag	RDOT_DATA_GOOD	*	D	-	ON,OFF	-	Filter rate
Time of rendezvous radar measurements	T_REND_RADAR	*	F	DP		Sec	Filter rate

* Rendezvous State and Covariance Measurement Incorporation Subfunction

TABLE 4.3.2.2-2 EXTERNAL SENSOR DATA SNAP OUTPUT PARAMETERS

DESCRIPTION	SYMBOL	OUTPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	COMPUTATION RATE
Rotation matrix, M50 to body at T_REND_RADAR	M_M50_TO_ BODY_RR	*	M	DP		-	Filter rate
Star tracker measured horizontal angle	Q_ST_HORIZ	*	F	DP		Rad	Filter rate
Star tracker measured vertical angle	Q_ST_VERT	*	F	DP		Rad	Filter rate
Star tracker measurement data good flag	ST_DATA_GOOD	*	D	-	ON,OFF	-	Filter rate
Star tracker identifier	N_ST_IN_USE	*	I	-	1,2		Filter rate
Time of star tracker measurement	T_STAR_TRACKER	*	F	DP		Sec	Filter rate
Rotation matrix, M50 to body at T_STAR_TRACKER	M_M50_TO_ BODY_ST	*	M	DP		_	Filter rate
COAS measured horizontal angle	Q_COAS_HORIZ	*	F	DP		Rad	Filter rate
COAS measured vertical angle	Q_COAS_VERT	*	F	DP		Rad	Filter rate
COAS measurement data good flag	COAS_DATA_ GOOD	*	D	-	ON,OFF	-	Filter rate

* Rendezvous State and Covariance Measurement Incorporation Subfunction

TABLE 4.3.2.2-2 EXTERNAL SENSOR DATA SNAP OUTPUT PARAMETERS (continued)

DESCRIPTION	SYMBOL	OUTPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	COMPUTATION RATE
COAS identifier	N_COAS_IN_USE	*	I	-	1,2	-	Filter rate
Time of COAS measurement	T_COAS	*	F	DP		Sec	Filter rate
Rotation matrix, M50 to body, at T_COAS	M_M50_TO_BODY_COAS	*	M	DP		-	Filter rate

* Rendezvous State and Covariance Measurement Incorporation Subfunction

4.3.2.3 Sensor Measurement Selection

A capability, designated as the rendezvous sensor measurement selection subfunction, is required to determine if external sensor measurement data will be presented to the state and covariance measurement incorporation subfunction (sec. 4.3.2.7) when the rendezvous navigation principal function is active. Selection of measurement data shall also mean that knowledge of this data selection will be provided to the measurement reconfiguration subfunction (sec. 4.3.2.4.1) to cause proper configuration of the state vector and covariance matrix.

A. Detailed requirements

The requirements for this subfunction are given as a set of necessary sensor measurement data selection capabilities. Only the following four sensor measurement data types will be considered for selection: rendezvous radar range and range rate, rendezvous radar angles (shaft and trunion), star tracker angles (horizontal and vertical), and COAS angles (horizontal and vertical). The following capabilities shall be provided.

1. All external sensor measurement processing shall be inhibited for a premission-determined time prior to the initiation of powered flight and during powered flight.

2. If external sensor measurement processing is not inhibited then rendezvous radar range and range rate data will be selected for processing and the crew shall be able to manually enable any one of the following sensor measurement data types: rendezvous radar angles data, star tracker angles data, or COAS angles data. The last enabled of these three angles data types shall be the only angles data type selected, i.e., the remaining two angles data types shall not be considered for selection.

3. The crew shall be able to manually force or inhibit the selection of sensor measurement data or to allow the selection process to be automatic. Manual forcing or inhibiting shall override the automatic selection criteria. For each of the three angle data types, forcing or inhibiting shall effect selection only if that angles data type is enabled.

4. If a crewman forces rendezvous radar range and range rate data or an enabled angles data type then the forced data will be presented to the state and covariance measurement subfunction and the residual edit test shall be overridden for that data type. If a crewman inhibits rendezvous radar range and range rate data or an enabled angles data type then the inhibited data will be processed for statistical display purposes only. The force or

inhibit of sensor measurement data shall remain in effect across major mode transitions and is removed by reverting to automatic selection.

5. If the automatic selection criteria is in effect for rendezvous radar range and range rate data or an enabled angles data type then these data will be selected for processing.

B. Interface requirements

The input and output parameters for this subfunction are indicated in tables 4.3.2.3-1 and 4.3.2.3-2, respectively.

C. Processing requirements

This subfunction shall be performed after sensor measurement data has been saved and before the measurement reconfiguration subfunction (sec. 4.3.2.4.1) is executed.

D. Constraints

The proper setting of the enable control for each of the angular data choices shall be performed by software external to navigation.

E. Supplementary information

The foregoing requirements indicate the existence of a pair of three-position software switches, i.e., two AUTO/INHIBIT/FORCE switches, one associated with rendezvous radar range and range rate data and another associated with the currently enabled angles measurement data. The existence of an individual

OFF/ON software switch for each of the angles data types to be used for enabling is also indicated.

A suggested implementation of this subfunction is shown in REND_SENSOR_SELECT CODE (appendix B).

TABLE 4.3.2.3-1 RENDEZVOUS SENSOR MEASUREMENT SELECTION INPUT PARAMETERS

DESCRIPTION	SYMBOL	INPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	SAMPLE RATE (1/SEC)
ON/OFF Flag used to indicate if external measurements should be processed	USE_MEAS_DATA	Rendezvous Nav Control Subfunction	D	S	OFF/ON		Filter Rate
Rendezvous radar range and range rate AUTO/INHIBIT/FORCE switch	RRDOT_AIF	*	CHAR	S			Filter Rate
Rendezes AUTO/INHIBIT/FORCE switch used for the currently enabled angle set	ANGLES_AI	*	CHAR	S			Filter Rate
Rendezvous radar angles ENABLE flag	RR_ANGLES_ENABLE	*	D	S			Filter Rate
COAS Angles ENABLE flag	COAS_ENABLE	*	D	S			Filter Rate
Star tracker angles ENABLE flag	ST_ENABLE	*	D	S			Filter Rate

*Rendezvous Navigation Principal Function Inlist

TABLE 4.3.2.3-2 RENDEZVOUS SENSOR MEASUREMENT SELECTION OUTPUT PARAMETERS

DESCRIPTION	SYMBOL	OUTPUT DESTINATION	TYPE	PRECISION	RANGE	UNITS	COMP RATE (1/SEC)
General edit indicator for I-th measurement type, I = 1, 5.	SENSOR_ EDIT	Rendezvous Measurement processing statistics	CHAR	S			Filter Rate
Flag used (ON) to override the residual edit test for rendezvous radar range and range rate	RRDOT_ EDIT_ OVER- RIDE	RRDOT data processing	D		OFF/ON		Filter Rate
Flag used (ON) to override the residual edit test for rendezvous radar angles	RR_ ANGLES_ EDIT_ OVER- RIDE	RR angles data processing	D		OFF/ON		Filter Rate
Flag used (ON) to override the residual edit test for star tracker angles	ST_ ANGLES_ EDIT_ OVER- RIDE	Star tracker angles data processing	D		OFF/ON		Filter Rate
Flag used (ON) to override the residual edit test for COAS angles	COAS_ ANGLES_ EDIT_ OVER- RIDE	COAS angles data processing	D		OFF/ON		Filter Rate

*Rendezvous control and Rendezvous measurement reconfiguration

TABLE 4.3.2.3-2 RENDEZVOUS SENSOR MEASUREMENT SELECTION OUTPUT PARAMETERS (CONT)

DESCRIPTION	SYMBOL	OUTPUT DESTINATION	TYPE	PRECISION	RANGE	UNITS	COMP. RATE (1/SEC)
Flag indicating (ON) that COAS angles data are to be processed for statistical display only	COAS_ANGLES_STAT	COAS angles data processing	D		OFF/ON		Filter Rate
Flag indicating (ON) that rendezvous radar range and range rate data are to be processed	DO_RRDOT_NAV	*	D		OFF/ON		Filter Rate
Flag indicating (ON) that rendezvous radar angles data are to be processed	DO_RR_ANGLES_NAV	*	D		OFF/ON		Filter Rate
Flag indicating (ON) that star tracker angles data are to be processed	DO_ST_ANGLES_NAV	*	D		OFF/ON		Filter Rate

*Rendezvous control and Rendezvous measurement reconfiguration

TABLE 4.3.2.3-2 RENDEZVOUS SENSOR MEASUREMENT SELECTION OUTPUT PARAMETERS (CONT)

DESCRIPTION	SYMBOL	OUTPUT DESTINATION	TYPE	PRECISION	RANGE	UNITS	COMP RATE (1/SEC)
Flag indicating (ON) that COAS angles data are to be processed	DO_COAS_ANGLES_NAV	*	D		OFF/ON		Filter Rate
Flag indicating (ON) that rendezvous radar range and range rate data are to be processed for statistical display only	RRDOT_STAT	RRDOT data processing	D		OFF/ON		Filter Rate
Flag indicating (ON) that rendezvous radar angles data are to be processed for statistical display only	RR_ANGLES_STAT	RR angles data processing	D		OFF/ON		Filter Rate
Flag indicating (ON) that star tracker angles data are to be processed for statistical display only	ST_ANGLES_STAT	Star tracker angles data processing	D		OFF/ON		Filter Rate

*Rendezvous control and Rendezvous measurement reconfiguration

4.3.2.4 State and Covariance Setup

This subfunction is required to perform the following two major tasks during operation of the rendezvous navigation principal function:

- set up the appropriate position, velocity, and unmodeled acceleration bias portion of the state vector and covariance matrix as a result of an automatic inflight update, and
- initialize and re-configure the sensor bias portion of the state vector and covariance matrix, as a result of sensor measurement type changes, or as a result of an automatic inflight update.

The following two subsections describe the requirements pertaining to the above tasks.

4.3.2.4.1 Measurement Reconfiguration

A capability shall be provided for initialization and reconfiguration of the sensor bias portion of the state vector and covariance matrix for the processing of measurements as required by the rendezvous sensor measurement selection subfunction (sec. 4.3.2.3). The measurement reconfiguration subfunction shall be performed when the measurement type configuration has changed to include new measurements or when an auto inflight update occurs while the rendezvous navigation principal function is active.

A. Detailed Requirements

The rendezvous sensor measurement selection subfunction shall provide a capability for determining when star tracker angles, COAS angles, rendezvous radar angles, or rendezvous radar range or range rate data are to be processed. The measurement reconfiguration subfunction determines whether a new measurement is to be made available; and if so, it reconfigures the bias portions of the state vector and covariance matrix to account for the change in measurement status. New exponentially correlated time constants and process noise variances are also selected from premision values for use in the computation of the state transition matrix and in the addition of process noise.

The state vector is to be reconfigured by setting its bias slots associated with the new measurement types to premission values. Bias values of measurement types no longer needed do not have to be zeroed unless the element slots of these values are needed by new measurement types. The covariance matrix is to be reconfigured by zeroing the off-diagonal terms associated with the new measurement type. The diagonal terms are then set equal to premission variance values of the new measurement types. The rows and columns associated with the discontinued measurement types do not have to be zeroed unless they are used by a new measurement type.

The accept/reject counters (N_ACCEPT,N_REJECT, SEQ_ACCEPT, SEQ_REJECT) for each measurement group must be reset to zero for use by the rendezvous measurement processing statistics subfunction (section 4.3.2.8).

The formulations required for reconfiguration of the state vector and covariance matrix are given before according to the sensor type. The measurement biases occupy the 16th through 19th element slots in the state vector. The last four rows and columns of the covariance matrix are associated with the uncertainties in these biases. A description of symbols used in the following equations may be found in tables 4.3.2.4.1-1 and 4.3.2.4.1-2.

Rendezvous radar angles

State vector:

$SENSOR\_BIAS_1 = 0$

$SENSOR\_BIAS_2 = 0$

Variance:

$VAR\_SENS\_DT_1 = VAR\_RR\_ANGLES\_DT_1$

$VAR\_SENS\_DT_2 = VAR\_RR\_ANGLES\_DT_2$

Covariance matrix:

$E_{16 \text{ to } 17,\ 1 \text{ to } 19} = 0$

$E_{1 \text{ to } 19,\ 16 \text{ to } 17} = 0$

$E_{16,\ 16} = VAR\_RR\_ANGLES_1$

$E_{17,\ 17} = VAR\_RR\_ANGLES_2$

Exponentially correlated time constant:

$TAU\_SENS_1 = TAU\_RR\_ANGLES_1$

$TAU\_SENS_2 = TA\_\_RR\_ANGLES_2$

$N\_ACCEPT_1 = 0$

$N\_REJECT_1 = 0$

$SEQ\_ACCEPT_1 = 0$

$SEQ\_REJECT_1 = 0$

Startracker angles

State vector:

$SENSOR\_BIAS_1 = 0$

$SENSOR\_BIAS_2 = 0$

Variance:

$VAR\_SENS\_DT_1 = VAR\_ST\_ANGLES\_DT_1$

$VAR\_SENS\_DT_2 = VAR\_ST\_ANGLES\_DT_2$

Covariance matrix:

$E_{16 \text{ to } 17,\ 1 \text{ to } 19} = 0$

$E_{1 \text{ to } 19,\ 16 \text{ to } 17} = 0$

$E_{16,\ 16} = VAR\_ST\_ANGLES_1$

$E_{17,\ 17} = VAR\_ST\_ANGLES_2$

Exponentially correlated time constants:

$TAU\_SENS_1 = TAU\_ST\_ANGLES_1$

$TAU\_SENS_2 = TAU\_ST\_ANGLES_2$

Accept/reject counters:

$N\_ACCEPT_1 = 0$

$N\_REJECT_1 = 0$

$SEQ\_ACCEPT_1 = 0$

$SEQ\_REJECT_1 = 0$

<u>Rendezvous radar range and range rate</u>

State vector:

$SENSOR\_BIAS_3 = 0$

$$SENSOR\_BIAS_4 = 0$$

Variance:

$$VAR\_SENS\_DT_3 = VAR\_RRDOT\_DT_1$$

$$VAR\_SENS\_DT_4 = VAR\_RRDOT\_DT_2$$

Covariance Matrix:

$$E_{18 \text{ to } 19, 1 \text{ to } 19} = 0$$

$$E_{1 \text{ to } 17, 18 \text{ to } 19} = 0$$

$$E_{18, 18} = VAR\_RRDOT_1$$

$$E_{19, 19} = VAR\_RRDOT_2$$

Exponentially correlated time constant:

$$TAU\_SENS_3 = TAU\_RRDOT_1$$

$$TAU\_SENS_4 = TAU\_RRDOT_2$$

Accept/reject counters:

$$N\_ACCEPT_{2 \text{ to } 3} = 0$$

$$N\_REJECT_{2 \text{ to } 3} = 0$$

$$SEQ\_ACCEPT_{2 \text{ to } 3} = 0$$

$$SEQ\_REJECT_{2 \text{ to } 3} = 0$$

COAS angles

State vector:

$$SENSOR\_BIAS_1 = 0$$

$$SENSOR\_BIAS_2 = 0$$

Variance:

$$VAR\_SENS\_DT_1 = VAR\_COAS\_ANGLES\_DT_1$$

$$VAR\_SENS\_DT_2 = VAR\_COAS\_ANGLES\_DT_2$$

Covariance matrix:

$$E_{16\text{ to }17,\ 1\text{ to }19} = 0$$

$$E_{1\text{ to }19,\ 16\text{ to }17} = 0$$

$$E_{16,\ 16} = VAR\_COAS\_ANGLES_1$$

$$E_{17,\ 17} = VAR\_COAS\_ANGLES_2$$

Exponentially correlated time constant:

$$TAU\_SENS_1 = TAU\_COAS\_ANGLES_1$$

$$TAU\_SENS_2 = TAU\_COAS\_ANGLES_2$$

Accept/reject counters:

$$N\_ACCEPT_1 = 0$$

$$N\_REJECT_1 = 0$$

$$SEQ\_ACCEPT_1 = 0$$

$$SEQ\_REJECT_1 = 0$$

The measurement reconfiguration subfunction shall also re-initialize the bias portion of the state vector and covariance matrix in the event of in-flight updates. This may be accomplished by considering all measurement types as new measurements.

B. Interface requirements

The input and output variables for this subfunction are described in tables 4.3.2.4.1-1 and 4.3.2.4.1-2.

C. Processing Requirements

The measurement reconfiguration subfunction shall be performed prior to processing of measurements and after the execution of the rendezvous sensor measurement selection subfunction.

D. Constraints

None.

E. Supplementary Information

A suggested implementation of the measurement reconfiguration subfunction is illustrated by the flow charts in Appendix B, REND_NAV_SENSOR_INIT CODE, RRDOT_SETUP CODE, RR_ANGLES_SETUP CODE, ST_ANGLES_SETUP CODE and COAS_ANGLES_SETUP CODE.

TABLE 4.3.2.4.1-1. Measurement Reconfiguration Input Parameters

DESCRIPTION	SYMBOL	INPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	SAMPLE RATE
Flag indicating that rendezvous radar range and range rate are to be processed	DO_RRDOT_NAV	Rendezvous sensor measurement selection	D		OFF ON		Filter rate
Flag indicating that rendezvous radar angles are to be processed	DO_RR_ANGLES_NAV	Rendezvous sensor measurement selection	D		OFF ON		Filter rate
Flag indicating that startracker angles are to be processed	DO_ST_ANGLES_NAV	Rendezvous sensor measurement selection	D		OFF ON		Filter rate
Flag indicating that COAS angles are to be processed	DO_COAS_ANGLES_NAV	Rendezvous sensor measurement selection	D		OFF ON		Filter rate
Premission values for the rendezvous radar range and range rate measurement bias variances	VAR_RRDOT_DT	premission load	V	DP		ft^2/sec, ft^2/sec^3	As needed
Premission values for the rendezvous radar angles measurements bias variances	VAR_RR_ANGLES_DT	premission load	V	DP		rad^2/sec	As needed
Premission values for the startracker angles measurements bias variances	VAR_ST_ANGLES_DT	premission load	V	DP		rad^2/sec	As needed

Table 4.3.2.4.1-1. (continued) Measurement Reconfiguration Input Parameters

DESCRIPTION	SYMBOL	INPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	SAMPLE RATE
Premission values for the COAS angles measurement bias variances	VAR_COAS_ANGLES_DT	premission load	V	DP		rad^2/sec	As needed
Rendezvous radar range and range rate measurement bias variance used to initialize the covariance matrix diagonal	VAR_RRDOT	premission load	V	DP		ft^2, ft^2/sec^2	As needed
Rendezvous radar angles measurement bias variances used to initialize covariance diagonals	VAR_RR_ANGLES	premission load	V	DP		rad^2	As needed
Startracker angles measurement bias variances used to initialize covariance diagonals	VAR_ST_ANGLES	premission load	V	DP		rad^2	As needed
COAS Angles measurement bias variances used to initialize the covariance diagonal	VAR_COAS_ANGLES	premission load	V	DP		rad^2	As needed
Correlation time constants for rendezvous radar range and range rate	TAU_RRDOT	premission load	V	DP		sec	As needed
Correlation time constants for rendezvous radar angles	TAU_RR_ANGLES	premission load	V	DP		sec	As needed

TABLE 4.3.2.4.1-1. (continued) Measurement Reconfiguration Input Parameters

DESCRIPTION	SYMBOL	INPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	SAMPLE RATE
Correlation time constants for startracker angles	TAU_ST_ANGLES	premission load	V	DP		sec	As needed
Correlation time constants for COAS angles	TAU_COAS_ANGLES	premission load	V	DP		sec	As needed

TABLE 4.3.2.4-2 Measurement Reconfiguration Output Parameters

DESCRIPTION	SYMBOL	OUTPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	COMPUTATION RATE
Filter covariance matrix	E	Rendezvous measurement incorporation	M	DP		VARY	Filter rate
General measurement bias filter variance used in propagation of biases and in adding process noise	VAR_SENS_DT	Rendezvous state and covariance propagation	V	DP		VARY	As needed
Sensor bias portion of the state vector	SENSOR_BIAS	Rendezvous state and covariance measurement incorporation	V	DP		VARY	Filter rate
General sensor measurement bias time constant	TAU_SENS	Rendezvous state and covariance	V	DP		sec	As needed
Sensor measurement ACCEPT counter	N_ACCEPT	Rendezvous measurement processing statistics	V				Filter rate
Sensor measurement REJECT counter	N_REJECT	Rendezvous measurement processing statistics	V				Filter rate

TABLE 4.3.2.4-2 (continued) Measurement Reconfiguration Output Parameters

DESCRIPTION	SYMBOL	OUTPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	COMPUTATION RATE
Sensor measurement sequential ACCEPT counter	SEQ_ACCEPT	Rendezvous measurement processing statistics	V				Filter rate
Sensor measurement sequential REJECT counter	SEQ_REJECT	Rendezvous measurement processing statistics	V				Filter rate

4.3.2.4.2 Auto In-Flight Update. This task is required to set up the proper state vector and covariance matrix as a result of an automatic inflight update during operation of the rendezvous navigation principal function. This task shall be capable of performing the following basic sub-tasks:

1. Predict uplinked orbiter state vector (M50 coordinates) to current time from uplinked time tag.
2. Initialize (6 x 6) orbiter position/velocity covariance matrix to pre-mission stored(or uplinked) UVW standard deviations and correlation coefficients, and initialize diagonal elements of the filter covariance matrix associated with the unmodeled acceleration bias errors, to pre-mission stored values (in body coordinates).
3. Predict uplinked target state vector (M50 coordinates) to current time from uplinked time tag.
4. Initialize (6 x 6) target position/velocity covariance matrix to pre-mission stored (or uplinked) UVW standard deviations and correlation coefficients.
5. Enable reinitialization of the sensor bias portion of the state vector and covarial matrix by setting the "DO_SENSOR_NAV_LAST" flags to zero.

A. Detailed Requirements. Section 4.2.5 contains a description of the detailed requirements for this task (the REND_NAV_FLAG will be in the ON setting, thus indicating those requirements necessary during operation of the rendezvous navigation principal function).

B. Interface Requirements. Input and output parameters are listed in the tables 4.3.2.4.2-1 and 4.3.2.4.2-2 respectively.

C. Processing Requirements. The state and covariance setup subfunction shall be performed each navigation cycle; however, the automatic inflight update task shall only be performed when a ground uplink has been received (i.e., the DO_AUTO_UPDATE flag has been set to ON by the ground uplink processor).

D. Constraints. The constraints are identical to those listed for the auot inflight update task during operation of the onorbit navigation principal function (see section 4.3.1.2).

E. Supplementary Information. A suggested implementation in the form of detailed flow charts can be found in Appendix B and C under the following names:

ONORBIT-REND-AUTO-INFLIGHT-UPDATE
ONORBIT-REND-STATE-AND-COV-SETUP (CODE)
ONORBIT-COVINIT-UVW
ACCEL-PERT-ONORBIT
} Appendix B

ONORBIT-PREDICT ~ Appendix C

Table 4.3.2.4.2-1 AUTO IN-FLIGHT UPDATE INPUT LIST

DESCRIPTION	SYMBOL	INPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	SAMPLE RATE
flag indicating (ON) that an automatic inflight update of either orbiter and/or target state and covariance matrix is to be performed.	DO_AUTO_UPDATE	*	D	-	ON/OFF	-	NAV rate
flag indicating whether rendezvous navigation active (ON) or onorbit navigation active (OFF)	REND_NAV_FLAG	*	D	-	ON/OFF	-	As rqd
flag set by ground uplink processor indicating (ON) that orbiter vehicle state vector has been uplinked	OV_UPLINK	*	D	-	ON/OFF	-	As rqd
flag set by ground uplink processor indicating (ON) that target vehicle state vector has been uplinked	TV_UPLINK	*	D	-	ON/OFF	-	As rqd
flag indicating degree of gravitational potential model	GM_DEG	**	I	S	1-8	-	As rqd

* rendezvous navigation principal function input list
** pre-mission load

Table 4.3.2.4.2-1 - (Continued) AUTO IN-FLIGHT UPDATE INPUT LIST

DESCRIPTION	SYMBOL	INPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	SAMPLE RATE
flag indicating order of gravitations potential model	GM_ORD	**	I	S	0-8	-	As rqd
flag which activates (1) or deactivates (0) the drag acceleration model	DRAG_MODE_NAV	**	I	S	0,1	-	As rqd
flag which activates (1) or deactivates (0) the venting and RCS-uncoupled-thrusting model	VENT_MODE_NAV	**	I	S	0,1	-	As rqd
integration step-size for precision state prediction	PREC_STEP	**	I	S	-	ft	As rqd
uplinked orbiter position vector (M50)	R_GND	*	V	DP	-	ft/sec	As rqd
uplinked orbiter state vector time tag	T_GND	*	F	DP	-	sec	As rqd

* rendezvous navigation principal function input list
** pre-mission load

Table 4.3.2.4.2-1 - (Continued) AUTO IN-FLIGHT UPDATE INPUT LIST

DESCRIPTION	SYMBOL	INPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	SAMPLE RATE
time tag of current filter state vector	T_CURRENT_	state propagation	F	DP	-	sec	As rqd
vector (6 x 1) of standard deviations (UVW) for orbiter position/velocity covariance initialization (ground update)	SIG_UPDATE	*,**	V	DP	-	vary	As rqd
vector (7 x 1) of correlation coefficients associated with UVW standard deviations SIG_UPDATE used for orbiter position/velocity covariance initialization (ground update)	COV_COR_UPDATE	*, **	V	DP	-1,1	-	As rqd
earth gravitational constant	EARTH_MU	**	F	DP	-	$\frac{ft^2}{sec^2}$	As rqd
vector (3 x 1) of unmodeled acceleration bias error variances (body coordinate system)	COV_ACCEL_BODY_INIT	**	V	DP	-	$\frac{ft^2}{sec^4}$	As rqd
uplinked target vehicle position vector (M50)	R_TV_GND	*	V	DP	-	ft	As rqd

* rendezvous navigation principal function input list
** pre-mission load

Table 4.3.2.4.2 - 1 - (Continued) AUTO In-FLIGHT UPDATE INPUT LIST

DESCRIPTION	SYMBOL	INPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	SAMPLE RATE
vector (6 x 1) of standard deviations (UVW) for target vehicle position/velocity covariance initialization (ground update)	SIG-TV-UPDATE	*, **	V	DP	-1,1	-	As rqd
(see section 4.8, I-Load Requirements)	(acceleration model and predictor constants)	**	-	-	-	-	As rqd

* rendezvous navigation principal function input list
** pre-mission load

TABLE 4.3.2.4.2-2 Auto In-Flight Update Output List

DESCRIPTION	SYMBOL	OUTPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	COMPUTATION RATE
flag indicating (ON) that an automatic inflight update has been performed	DID_AUTO_UPDATE	*	D	-	ON/OFF	-	NAV rate
orbiter position vector (M50)	R_FILT	state propagation, covariance propagatopm. rendezvous control, state and covariance measurement incorporation	V	DP	-	ft	As rqd
orbiter velocity vector (M50)	V_FILT	state propagation, covariance propagation	V	DP	-	ft/sec	As rqd
vector of orbiter total acceleration (M50)		state propagation	V	DP	-	ft/sec^2	As rqd
vector (3 x 1) of unmodeled acceleration bias errors (body coord. systems)	VENT_THRUST_BIAS	state propagation	V	DP	-	ft/sec^2	As rqd
filter covariance matrix of orbiter position, velocity, and unmodeled acceleration bias errors (9 x 9 dimensional)	E	covariance propagation	M	DP	-	vary	As rqd

* rendezvous navigation principal function output list

ORIGINAL PAGE IS OF POOR QUALITY

TABLE 4.3.2.4.2-2 (continued) Auto In-Flight Update Output List

DESCRIPTION	SYMBOL	OUTPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	COMPUTATION RATE
target vehicle position vector (M50)	R-TV	state propagation, rendezvous control, covariance propagation, state and covariance meas. incorp.	V	DP	-	ft	As rqd
target vehicle velocity vector (M50)	V TV	state propagation, rendezvous control, covariance propagation, state and covariance meas. incorp.	V	DP	-	ft/sec	As rqd
flag indicating (ON) the availability of a target vehicle state vector and time tag for re-initialization purposes	TARG VEC_ AVAIL	*	D	-	ON/OFF	-	As rqd
target vehicle total acceleration vector (M50)	G TV	state propagation,	V	DP	-	ft/sec^2	As rqd

* Rendezvous navigation principal function output list

Table 4.3.2.4.2-2 AUTO IN-FLIGHT UPDATE OUTPUT LIST (concluded)

DESCRIPTION	SYMBOL	OUTPUT DESTINATION	TYPE	PRECISION	RANGE	UNITS	SAMPLE RATE
flag indicating (ON) that COAS angles data was selected for processing on last nav. cycle	DO_COAS_ANGLES_NAV_LAST	measurement reconfiguration	D	-	ON/OFF	-	As rqd
flag indicating (ON) that rendezvous radar angles was selected for processing on last nav. cycle	DO_RR_ANGLES_NAV_LAST	measurement reconfiguration	D	-	ON/OFF	-	As rqd
flag indicating (ON) that rendezvous radar range and range-rate data was selected for processing on last nav. cycle	DO_RRDOT_NAV_LAST	measurement reconfiguration	D	-	ON/OFF	-	As rqd
flag indicating (ON) that star tracker angles data was selected for processing on last nav. cycle	DO_ST_ANGLES_NAV-LAST	measurement reconfiguration	D	-	ON/OFF	-	As rqd

* rendezvous navigation principal function output list

4.3.2.5 State Propagation

This subfunction will perform a number of tasks related to the propagation of the orbiter and target state vectors.

The task of reading (snapping) the IMU shall be performed to obtain the current time and the accumulated sensed velocity. Details of the IMU snap task are to be found in section 4.2.1.1.

Available acceleration models include gravitational accelerations (always used) and non-gravitational accelerations (drag, venting, and uncoupled RCS thrusting). The latter shall be used in those circumstances in which sensed accelerations obtained from the IMU accumulated sensed velocities are judged to be insignificant. These acceleration models are described in detail in section 4.2.1.2.

The equations of motion will be integrated with either a super-g algorithm (see section 4.2.1.2.1) intended primarily for powered flight phases (i.e., those phases in which significant non-gravitational accelerations are sensed) or a precision propagation algorithm designed specifically for coasting flight phases and described in detail in section 4.2.1.3.2.

The task of propagation of biases shall be performed by multiplying the previous value of each bias by unity. Three biases propagated in this way represent unmodeled acceleration; the other 4 are the rendezvous sensor biases.

A. Detailed Requirement

The requirements of this subfunction for the propagation of positions and velocities, follow closely those of section 4.3.1.3. They shall be described here step by step, even though most of these steps are identical to those described in section 4.3.1.3.

1. The IMU shall be snapped (see section 4.2.1.1 for details of this task)

2. Values of the orbiter's position and velocity vectors calculated in the previous navigation cycle, together with the respective time tag and total acceleration shall be saved for use in the current cycle:

   $\underline{\text{TOT\_ACC\_LAST}} = \underline{\text{TOT\_ACC}}$

   $\underline{\text{R\_LAST}} = \underline{\text{R\_FILT}}$

   $\underline{\text{V\_LAST}} = \underline{\text{V\_FILT}}$

3. The time interval for advancement of both orbiter and target state vectors shall be calculated by subtracting the time tag of the previous cycle from the time (T_CURRENT_FILT) obtained from the IMU snap:

   DT_FILT = T_CURRENT_FILT - T_LAST_FILT

4. The flag that indicates the choice of integrator for the orbiter state vector propagation shall then be tested. This flag, PWRD_FLT_NAV, is set by the on-orbit/rendezvous navigation sequencer principal function. It is set to OFF when in a coasting flight phase

of the operations, and set to ON just before a burn occurs in the orbiter (no thrusters are anticipated in the target vehicle).

4.1 If the flag is found to be ON, the super-g integrator shall be invoked for advancement of the orbiter state. This requires the setting of certain flags. It also requires comparing the acceleration calculated from the IMU sensed velocities with a pre-stored threshold value below which this acceleration shall be ignored.

So, the following steps are needed:

4.1.1 Find the difference in the accumulated sensed velocity

$$\underline{DV}\_FILT = \underline{V}\_CURRENT\_FILT - \underline{V}\_LAST\_FILT$$

4.1.2 Calculate an acceleration magnitude from $\underline{DV}$_FILT and DT_FILT and compare it with the threshold value:

$$\frac{|\underline{DV}\_FILT|}{DT\_FILT} > DA\_THRESHOLD$$

Then, if the calculated acceleration is larger than the threshold value, set the following flags:

USE_IMU_DATA = ON

IGD = GM_LOW

IGO = GM_LOW

IDRAG = 0

IVENT = 0

and set

DV = DV_FILT

On the other hand, if the calculated absolute value of the acceleration is below the threshold level, set

USE_IMU_DATA = OFF

IGD = GM_DEG

IGO = GM_ORD

IDRAG = 1

I VENT = 1

and

DV = 0.

4.1.3 Find a value of the sensed acceleration based on DV (it could, therefore, be 0., thus ignoring the IMU readings)

A_SENS = DV/DT_FILT

4.1.4 Call the super-g integrator (see section 4.2.1.3.1 for detailed requirements) with the flag values just set:

CALL: ONORBIT_SUPER_G

IN LIST: IGD, IGO, IDRAG, IVENT, 0, R_FILT,
V_FILT, T_CURRENT_FILT, DT_FILT, DV

OUT LIST: R_FILT, V_FILT, G_NEW

4.2 . In the situation where the PWRD_FLT_NAV is found to be OFF, the precision propagation integration scheme shall be called to advance the orbiter state. The sequence, in this case, shall be as follows:

4.2.1 Check the REND_NAV_FLAG, and choose the step-size for the precision propagator according to the values of this flag. The step-size does affect the accuracy of the integration, and it is natural that the accuracy requirements during the rendezvous phases be different from those in other phases of the orbital operations. The REND_NAV_FLAG, during the periods in which the Rendezvous Navigation principal function is in operation, shall always be found to be ON. This will result in setting

DT = REND_STEP

4.2.2 The vector A_SENS is required for the computation of TOT_ACC in a later step. The precision propagator being a coasting flight integrator, the sensed accelerations are not needed by it. Therefore, set

A_SENS = 0.

4.2.3 Invoke the precision propagator (see section 4.2.1.3.2 for detailed requirements) with calling arguments that will cause the modeling of drag, venting and uncoupled

thrusting accelerations, with the use of current attitude information.

CALL: ONORBIT_PRECISE_PROP

IN LIST: GM_DEG, GM_ORD, 1, 1, 0, DT, R_FILT,
V_FILT, T_LAST_FILT, T_CURRENT_FILT

OUT LIST: R_FILT, V_FILT, G_NEW

At the end of either step 4.1.4 or step 4.2.3, the values of R_FILT and V_FILT output by the corresponding integrator are the required propagated position and velocity vectors of the orbiter. The vector G_NEW is a modeled acceleration vector obtained according to the specified flag settings and corresponding to R_FILT, V_FILT and T_CURRENT_FILT.

5. The REND_NAV_FLAG shall then be tested. This flag indicates whether or not it is necessary to also propagate the state vector of the target vehicle. While the Rendezvous Navigation principal function is operative, this flag will always have the value ON, and propagation of the target state vector will be required.

Propagation of the target vehicle state vector shall be achieved with the use of the precision propagator subfunction. The flag settings for the necessary calls to the acceleration function shall be such as to cause drag to be modeled (drag mode flag set to 1), the mass, drag

coefficient and cross-sectional area of the target vehicle to be used in the calculations are specified by setting the attitude mode flag to 3, venting and uncoupled thrusting are to be ignored (venting mode flag set to 0), and degree and order flags for gravitational accelerations are to be equal to those used by the precision propagation for the orbiter state advancement. Values of the target vehicle's position, velocity, and acceleration vectors from the previous cycle are needed. Therefore,

5.1 Save the above mentioned vectors for use in the current cycle:

G_TV_LAST = G_TV

R_TV_LAST = R_TV

V_TV_LAST = V_TV

5.2 Use the precision propagation subfunction to advance the target vehicle's position and velocity vectors and to obtain a corresponding total acceleration vector (which coincides with the modeled acceleration, there being no propulsive devices in the target).

CALL: ONORBIT_PRECISE_PROP

IN LIST: GM_DEG, GM_ORD, 1, 0, 3, DT,
R_TV, V_TV, T_LAST_FILT, T_CURRENT_FILT

OUT LIST: R_TV, V_TV, G_TV

6. Save the IMU readings for the next cycle. The V_CURRENT_FILT will only be needed for the orbiter state propagation, but

the T_CURRENT_FILT will be used to determine the advancement interval for both vehicle's states. Also, find the total acceleration vector for the orbiter (required for covariance transition matrix calculations).

T_LAST_FILT = T_CURRENT_FILT

V_LAST_FILT = V_CURRENT_FILT

TOT_ACC = G_NEW + A_SENS.

B. Interface Requirements

Input and output parameters are to be found in Tables 4.3.2.5-1 and 4.3.2.5-2 respectively.

C. Processing Requirements

None.

D. Constraints

The acceleration models task is needed not only by the navigation state propagation subfunction but also by the onorbit precision state prediction principal function and by the user parameter state propagation subfunction. Each of these users of the acceleration models shall set its own flags and therefore require a different calculation. To protect against interference in the acceleration computations, it is important that these computations not be interrupted.

E. Supplementary information.

A suggested implementation of this subfunction, in the

form of detailed flow diagrams, may be found in Appendix B:

ONORBIT_REND_R_V_STATE_PROP

ONORBIT_SUPER_G

ONORBIT_PRECISE_PROP

NAV_RENDEZVOUS (IMU snap portion)

ONORBIT_REND_BIAS_AND_COV_PROP (CODE)

TABLE 4.3.2.5-1 RENDEZVOUS STATE PROPAGATION INPUT PARAMETERS

DESCRIPTION	SYMBOL	INPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	SAMPLE RATE
Copy of V_IMU CURRENT raw velocity counts reserved for measurement processing	V_CURRENT_FILT	*	V	DP		Ft/sec	Filter rate
MTU or clock time when IMU was read	T_CURRENT_FILT	*	F	DP		Sec	Filter rate
Angle of attack	ALPHA	*	F	DP	0-2Π	Rad	Filter rate
Flag indicating choice of integrator for orbiter state propagation	PWRD_FLT_NAV	*	D	S	ON, OFF	-	As Needed
Filter current orbiter position vector in M50 coordinates	R_FILT	*, Rendezvous state and covariance set-up. Auto in-flight update.	V	DP		Ft	Filter rate
Target state vector in M50 coordinates	R_TV	*, Rendezvous state and covariance set-up, Auto in-flight update	V	DP		Ft	Filter rate
Total acceleration (sensed plus modeled) of orbiter.	TOT_ACC	*,	V	DP		Ft/sec^2	Filter rate

* Rendezvous Navigation Principal Function Input List
** Premission loaded
*** These constants are listed and their values given in Section 4.8 (I-load requirement).

ORIGINAL PAGE IS OF POOR QUALITY

TABLE 4.3.2.5-1 RENDEZVOUS STATE PROPAGATION INPUT PARAMETERS

DESCRIPTION	SYMBOL	OUTPUT DESTINATION	TYPE	PRECISION	RANGE	UNITS	SAMPLE RATE
Acceleration of target vehicle	G_TV	*, Rendezvous state prop.	V	DP		Ft/sec^2	Filter Rate
Flag indicating if the current nav. phase is a rendezvous phase	REND_NAV_FLAG	*	D	-	ON, OFF	-	As needed
Orbiter velocity vector	V_FILT	*, Rendezvous state and covariance setup, Auto in-flight update	V	DP		Ft/sec	Filter Rate
Target velocity vector	V_TV	*, Rendezvous state and covariance setup. Auto in-flight update	V	DP		Ft/sec	Filter Rate
Angle of sideslip	BETA	*	F	DP	0-2π	Rad	Filter Rate
Acceleration model related constants	***	**					

* Rendezvous Navigation Principal Function Input List
** Premission Load
*** These constants are listed and their values given in section 4.8 (I-load requirements).

TABLE 4.3.2.5-2 RENDEZVOUS STATE PROPAGATION OUTPUT PARAMETERS

DESCRIPTION	SYMBOL	OUTPUT DESTINATION	TYPE	PRECISION	RANGE	UNITS	COMPUTATION RATE /SEC
Filter current orbiter position vector in M50 coordinates	R_FILT	*, **	V	DP		Ft	Filter rate
Target vehicle position vector	R_TV	*, **	V	DP		Ft	Filter rate
Total acceleration (sensed plus modeled)	TOT_ACC	**	V	DP		Ft/sec^2	Filter rate
Acceleration of target vehicle	G_TV	*, **	V	DP		Ft/sec^2	Filter rate
Orbiter velocity vector	V_FILT	*, **	V	DP		Ft/sec	Filter rate
Target vehicle velocity vector	V_TV	*, **	V	DP		Ft/sec	Filter rate
Time of the filter state vector	T_LAST_FILT	Rendezvous nav.	F	DP		Sec	Filter rate
Flag indicating IMU acceleration threshold level	USE_IMU_DATA	*	D	-	ON-OFF	-	As needed

* Rendezvous Navigation Principal Function Output List

** Rendezvous Covariance Propagation

TABLE 4.3.2.5-2 RENDEZVOUS STATE PROPAGATION OUTPUT PARAMETERS (cont'd)

DESCRIPTION	SYMBOL	INPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	SAMPLE RATE
Previous total acceleration of orbiter	TOT_ACC_LAST	**	V	DP		Ft/sec^2	Filter rate
Previous position vector of orbiter	R_LAST	**	V	DP		Ft	Filter rate
Previous velocity vector of orbiter	V_LAST	**	V	DP		Ft/sec	Filter rate
Previous acceleration of target	G_TV_LAST	**	V	DP		Ft/sec^2	Filter rate
Previous position vector of target	R_TV_LAST	**	V	DP		Ft	Filter rate
Previous velocity vector of target	V_TV_LAST	**	V	DP		Ft/sec	Filter rate
Difference between two consecutive times snapped from the IMU	DT_FILT	**	F	DP		Sec	Filter rate
Time of the current state vectors	T_CURRENT_FILT	**	F	DP		Sec	Filter rate
Previous IMU accumulated sensed velocity	V_LAST_FILT	Rendezvous Nav.	V	DP		Ft/sec	Filter rate
Difference between two consecutive accumulated sensed velocities snapped from the IMU	DV_FILT	**	V	DP		Ft/sec	Filter rate

** Rendezvous Covariance Propagation Subfunction

4.3.2.6 Covariance Matrix Propagation

The covariance matrix propagation subfunction propagates the covariance matrix forward in time. The covariance matrix is propagated by utilizing the state transition matrix. Additive process noise is incorporated to account for unmodeled state and dynamic errors.

A. Detailed Requirements

A 19 by 19 covariance matrix shall be propagated with the rendezvous navigation principal function. This covariance matrix defines the uncertainty in the state vector, which consists of position and velocity of the orbiter, unmodeled accelerations, position and velocity of the target, and sensor measurement biases. The method of propagation is described in Section 4.2.2

B. Interface Requirements.

The input and output data are shown in Tables 4.3.2.6-1 and 4.3.2.6-2.

C. Processing Requirements.

This subfunction will be called after the IMU sensor data have been read and after the state propagation subfunction has been executed.

D. Constraints.

None.

E. Supplementary Information

A possible implementation of this subfunction is shown in the flow charts ONORBIT_REND_BIAS_AND_COV_PROP (CODE), PWRD_FLT_COV_PROP (CODE), REND_COV_PROP (CODE), MEAN_CONIC_PARTIAL_TRANSITION_MATRIX_6X6, and F_ANG_G in Appendix B.

TABLE 4.3.2.6-1 RENDEZVOUS COVARIANCE PROPAGATION INPUT PARAMETERS

DESCRIPTION	SYMBOL	INPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	SAMPLE RATE
Interval over which to propagate the covariance matrix	DT_FILT	state propagation	F	S		sec	filter rate
Correlation time constants for body venting	TAU_VENT	premission constant	V	S		sec	filter rate
Variance of body venting variables	VAR_VENT_DT	premission load	V	S		$(ft/sec^2)^2/sec$	filter rate
Structural body to M50 coordinate transformation matrix	M_SBODY_M50	*	M	S			filter rate
Drag acceleration coefficient perfect error	D_COE_PCT_ERR	premission load	F	S			filter rate
Drag acceleration vector	D	state propagation	V	S		ft/sec	filter rate
Flag indicating (ON) whether the rendezvous principal function is scheduled	REND_NAV_FLAG	*	D	-	ON/OFF		filter rate

* Rendezvous Navigation Principal Function Input List

TABLE 4.3.2.6-1 (Continued) RENDEZVOUS COVARIANCE PROPAGATION INPUT PARAMETERS

DESCRIPTION	SYMBOL	INPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	SAMPLE RATE
Filter current shuttle position vector in M50 coordinates	R_FILT	state propagation	V	DP		ft	filter rate
Filter current shuttle velocity vector in M50 coordinates	V_FILT	state propagation	V	DP			filter rate
Gravity acceleration at end of shuttle state integration interval	TOT_ACC	state propagation	V	DP		ft/sec^2	filter rate
Filter covariance matrix	E	measurement incorporation	M	DP		vary	filter rate
Flag indicating (ON) the desire to inhibit the processing of external measurement data by the navigation filter	PWRD_FLT_NAV	*		DP			filter rate

* Rendezvous Navigation Principal Function Input List

TABLE 4.3.2.6-1 (Continued) RENDEZVOUS COVARIANCE PROPAGATION INPUT PARAMETERS

DESCRIPTION	SYMBOL	INPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	SAMPLE RATE
Gravitational constant of the earth	EARTH-MU	premission load	F	S		$(ft^3/sec)^2$	filter rate
Square root of EARTH_MU	SQR_EMU	premission load	F	DP		ft^3/sec	filter rate
Identity matrix (3 x 3)	ID-MATRIX_3X3	premission load	M	DP			filter rate
Tolerance for succesive iterations in the solution of Kepler's equation	EPS-KEP	premission load	F	DP		rad	filter rate
Position vector of shuttle at the end of the last filter cycle	R_LAST	state propagation	V	DP		ft	filter rate
Velocity vector of shuttle at the end of the last filter cycle	V_LAST	state propagation	V	DP		ft/sec	filter rate
Gravity acceleration at start of shuttle state integration interval	TOT-ACC_LAST	state propagation	V	DP		ft/sec^2	filter rate

Table 4.3.2.6-1 (continued) RENDEZVOUS COVARIANCE PROPAGATION INPUT PARAMETERS

DESCRIPTION	SYMBOL	OUTPUT DESTINATION	TYPE	PRECISION	RANGE	UNITS	SAMPLE RATE
Difference between accumulated sensed IMU readings on present cycle and previous cycle	DV_FILT	state propagation	F	DP		ft/sec	Filter rate
Variance for platform misalignment added as process noise in the covariance	VAR_IMU_ALIGN	premission load	V	DP		rad^2	Filter rate
Time tag of the current filter state vector	T_LAST_FILT	state propagation	F	DP		sec	Filter rate
Time of the last IMU alignment	T_ALIGN	premission load	F	DP		sec	Filter rate
Variance of the platform drift	VAR_IMU_DRIFT	premission load	V	DP		rad^2	Filter rate
Accelerometer quantization error variance	VAR_ACC_QUANT	premission load	F	DP		ft^2/sec^2	Filter rate
Variance of unmodeled acceleration times scale time	VAR_UNMOD_ACC_DT	premission load	F	DP		ft^2/sec^3	Filter rate

TABLE 4.3.2.6-1 (continued) RENDEZVOUS COVARIANCE PROPAGATION INPUT PARAMETERS

DESCRIPTION	SYMBOL	INPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	SAMPLE RATE
Sensor measurement bias correlation time constants	TAU_SENS	Measurement reconfiguration	V	DP		sec	filter rate
Sensor measurement bias error variance	VAR_SENS_DT	Measurement reconfiguration	V	DP		vary	filter rate
Filter estimated target position at the end of the last filter cycle.	R_TV_LAST	State propagation	V	DP		ft	filter rate
Filter estimated target velocity at the end of the last filter cycle.	V_TV_LAST	State propagation	V	DP		ft/sec	filter rate
Gravity vector for the target at the beginning of the last integration interval	G_TV_LAST	State propagation	V	DP		ft/sec^2	filter rate
Current target position in M50 coordinates	R_TV	State propagation	V	DP		ft	filter rate
Current target velocity vector in M50 coordinates	V_TV	State propagation	V	DP		ft/sec	filter rate
Target's gravity vector at the end of the last integration interval	G_TV	State propagation	V	DP		ft/sec^2	filter rate

TABLE 4.3.2.6-2 RENDEZVOUS COVARIANCE PROPAGATION OUTPUT PARAMETERS

DESCRIPTION	SYMBOL	OUTPUT DESTINATION	TYPE	PRECISION	RANGE	UNITS	SAMPLE RATE
Filter convariance matrix	E	measurement incorporation	M	DP		vary	filter rate

4.3.2.7 State and Covariance Measurement Incorporation

The state and covariance measurement incorporation subfunction updates the state vector and covariance matrix with navigation data using a 19 state process noise Kalman filter.

A. Detailed Requirements

The state and covariance measurement incorporation subfunction is exercised only if data are available for processing as determined by the sensor measurement selection subfunction (Section 4.3.2.3) and the respective measurement subfunctions (Sections 4.3.2.7.1 through 4.3.2.7.8). The sensor measurement selection subfunction determines which measurement types are to be considered for processing. The measurement subfunctions process sensor data that are labeled as valid.

The particular measurement subfunction shall first compute the estimated measurement based on the state vector and the measurement residual. The measurement subfunction then calculates the first partial derivatives of the measurement with respect to the state, as well as the appropriate variance to model the uncorrelated instrument error. Rendezvous radar range and range rate, rendezvous radar shaft and trunion angles, COAS angles, and startracker angles will be available

for processing by the rendezvous navigation principal function.

Once a particular measurement subfunction has completed processing valid data, the filter control flags shall be set as follows:

<u>Rendezvous radar range and range rate</u>

MANUAL_EDIT_OVERRIDE = RRDOT_EDIT_OVERRIDE

STAT_FLAG = RRDOT_STAT

<u>Rendezvous radar shaft and trunion</u>

MANUAL_EDIT_OVERRIDE = RR_ANGLES_EDIT_OVERRIDE

STAT_FLAG = RR_ANGLES_STAT

<u>COAS angles</u>

MANUAL_EDIT_OVERRIDE = COAS_ANGLES_EDIT_OVERRIDE

STAT_FLAG = COAS_ANGLES_STAT

<u>Startracker angles</u>

MANUAL_EDIT_OVERRIDE = ST_ANGLES_EDIT_OVERRIDE

STAT_FLAG = ST_ANGLES_STAT

The state and covariance measurement incorporation subfunction shall then update the state and covariance matrix provided that either the residual edit criterion is met or the crew edit override for the particular sensor type is active, as described in section 4.2.4.

The following data shall then be stored after the particular

measurement type has been processed for subsequent computation of measurement processing statistics as described in section 4.3.2.8.

$SENSOR\_EDIT_I = EDIT\_FLAG$

$SENSOR\_RESID\_TEST_I = RESID\_TEST$

$SENSOR\_DELQ_I = DELQ$

where

I = 1 for startracker horizontal angle

I = 2 for startracker vertical angle

I = 1 for COAS horizontal angle

I = 2 for COAS vertical angle

I = 1 for rendezvous radar shaft angle

I = 2 for rendezvous radar trunion angle

I = 3 for rendezvous radar range

I = 4 for rendezvous radar range rate

B. Interface Requirements

The inputs and outputs for this subfunction are given in Tables 4.3.2.7-1 and 4.3.2.7-2.

C. Processing Requirements

This subfunction is not exercised until the external data snap, sensor measurement selection, state and covariance matrix setup, and state and covariance matrix propagation subfunctions have been performed; and the measurement pro-

cessing statistics subfunction cannot be initiated until this subfunction is completed.

D. Contraints

There is no requirement in the state and covariance measurement incorporation subfunction to perform updating if the data validity flags indicate bad data. No manual override of these flags exists in this subfunction. If it is desired to process a particular measurement, the data validity flag must be made to indicate that the data are valid.

E. Supplementary Information

A suggested implementation of the state and covariance measurement incorporation subfunction is presented in the flow charts of Appendix B, NAV_RENDEZVOUS, REND_NAV_FILTER and REND_STATE_AND_COV_UPDATE.

TABLE 4.3.2.7.-1. - State and Covariance Measurement Incorporation Input Parameters

DESCRIPTION	SYMBOL	INPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	SAMPLE RATE
Filter current shuttle position vector in M50 coordinates	R_FILT	state propagation	V	DP		ft	Filter rate
Filter current shuttle velocity vector in M50 coordinates	V_FILT	state propagation	V	DP		ft/sec	Filter rate
Filter estimate of the unmodeled accelerations on the orbiter	VENT_THRUST_BIAS	state propagation	V	DP		ft/sec^2	Filter rate
Current target position vector in M50 coordinates	R_TV	state propagation	V	DP		ft	Filter rate
Current target velocity vector in M50 coordinates	V_TV	state propagation	V	DP		ft/sec	Filter rate
The filter estimated sensor bias	SENSOR_BIAS	state propagation	V	DP		VARY	Filter rate
Filter covariance matrix	E	Rendezvous covariance propagation	M	DP		VARY	Filter rate
Measurement first partials with respect to filter state	B	Measurement subfunctions	V	DP		VARY	Filter rate
General sensor variance	VAR	Measurement subfunctions	F	DP			Filter rate

TABLE 4.3.2.7-1 (continued) - State and Covariance Measurement Incorporation Input Parameters

DESCRIPTION	SYMBOL	INPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	SAMPLE RATE
General measurement residual	DELQ	Measurement subfunction	F	DP		ft	Filter rate
Scale factor on filter mean square residual used in residual edit test	K_RES_EDIT	Premission load	F	DP			Filter rate
Switch used (ON) to override the automatic editing of rendezvous radar range and range rate measurements	RRDOT_EDIT_OVERRIDE	Sensor measurement selection	D		ON OFF		Filter rate
Switch used (ON) to override the automatic editing of rendezvous radar angles	RR_ANGLES_EDIT_OVERRIDE	Sensor measurement selection	D		ON OFF		Filter rate
Switch used (ON) to override the automatic editing of startracker angles measurements	ST_ANGLES_EDIT	Sensor measurement selection	D		ON OFF		Filter rate
Switch used (ON) to override the automatic editing of COAS angles measurements	COAS_ANGLES_EDIT_OVERRIDE	Sensor measurement selection	D		ON OFF		Filter rate
Switch used (ON) to indicate that rendezvous radar range and range rate data are to be processed for statistics only	RRDOT_STAT	Sensor measurement selection	D		ON OFF		Filter rate

TABLE 4.3.2.7-1 (continued) - State and Covariance Measurement Incorporation Input Parameters

DESCRIPTION	SYMBOL	INPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	SAMPLE RATE
Switch used (ON) to indicate that rendezvous radar angles data are to be processed for statistics only	RR_ANGLES_STATE	Sensor measurement selection	D		ON OFF		Filter rate
Switch used (ON) to indicate that startracker angles data are to be processed for statistics only	ST_ANGLES_STAT	Sensor measurement selection	D		ON OFF	—	Filter rate
Switch used (ON) to indicate that COAS angles data are to be processed for statistics only	COAS_ANGLES_STAT	Sensor measurement selection	D		ON OFF		Filter rate

TABLE 4.3.2.7-2. - State and Covariance Measurement Incorporation Output Parameters

DESCRIPTION	SYMBOL	OUTPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	COMPUTATION RATE
Filter covariance matrix	E	Rendezvous Covariance propagation	M	DP		vary	Filter rate
Filter current Shuttle position vector in M50 coordinates	R_FILT	state propagation	V	DP		ft	Filter rate
Shuttle velocity vector	V_FILT	state propagation	V	S		ft/sec	Filter rate
Filter estimate of the unmodeled acceleration on the orbiter	VENT_THRUST_BIAS	state propagation	V	DP		ft/sec^2	Filter rate
Current target position vector in M50 coordinates	R_TV	state propagation	V	DP		ft	Filter rate
Current target velocity vector in M50 coordinates	V_TV	state propagation	V	DP		ft/sec	Filter rate
The filter estimated sensor bias	SENSOR_BIAS	state propagation	V	DP		VARY	Filter rate
Edit indicators for measurements	SENSOR_EDIT	*	V				Filter rate
Measurement residuals	SENSOR_DELQ	*	V	DP		VARY	Filter rate
Value of criterion used in Nav filter for residual edit tests for the sensor measurements	SENSOR_RESID_TEST	*	V	DP		VARY	Filter rate

* Rendezvous Navigation Principal Function Out List

4.3.2.7.1 Rendezvous Radar Range

The rendezvous radar range measurement subfunction computes an estimated range from orbiter to target vehicle, the range residual, and the range measurement partial vector, and selects the proper variance to model the uncorrelated instrument error. This subfunction is performed only when rendezvous radar range data are indicated valid.

A. <u>Detailed Requirements</u>

A description of the symbols used in the following equations may be found in tables 4.3.2.7.1-1 and 4.3.2.7.1-2.

First the orbiter state vector shall be interpolated to the time of the range measurement with the use of the state vector interpolation subfunction as described in section 4.2.3. The following parameters must be given the values indicated before the interpolation can be exercised.

$\underline{R}$_ONE = $\underline{R}$_LAST

$\underline{V}$_ONE = $\underline{V}$_LAST

$\underline{R}$_TWO = $\underline{R}$_FILT

$\underline{V}$_TWO = $\underline{V}$_FILT

T_TWO = T_CURRENT_FILT

$\underline{V}$_IMU_DIF = $\underline{DV}$_FILT

T_DIF = DT_FILT

DTGO = DELTAT_GO

Next the position-velocity state transition submatrix subfunction is used to construct an orbiter patch transition matrix as described in section 4.2.8 for use in the measurement partial calculations. The following associations are required prior to execution.

R_ONE = R_FILT

V_ONE = V_FILT

G_ONE = TOT_ACC

R_TWO = R_RESID

V_TWO = V_RESID

G_TWO = A_RESID

DELTIM = DELTAT_GO

Then after the mean conic partial subfunction has been performed:

PHI_PATCH = PHI_MC

Then the target vector is interpolated to the time of the measurement as described in section 4.2.3. The following parameters must be given the values indicated before the interpolation can be exercised.

R_ONE = R_TV_LAST

V_ONE = V_TV_LAST

R_TWO = R_TV

where

DELTAT_GO = T_CURRENT_FILT_T_REND_RADAR

and

SENSOR_ID = 1

V_TWO = V_TV

T_TWO = T_CURRENT_FILT

V_IMU_DIF = 0

T_DIF = DT_FILT

DTGO = DELTAT_GO

The interpolation is performed for the target with drag modeled, but not venting. The results of the interpolation in section 4.2.3 are associated with target vector parameters as follows.

R_TV_RESID = R_RESID

V_TV_RESID = V_RESID

A_TV_RESID = A_RESID

Next the position-velocity state transition submatrix subfunction is used to construct a target patch transition matrix as described in section 4.2.8 for use in the measurement partials calculation. The following associations are required prior to execution.

R_ONE = R_TV

V_ONE = V_TV

G_ONE = G_TV

R_TWO = R_TV_RESID

V_TWO = V_TV_RESID

$\underline{G}$_TWO = $\underline{A}$_TV_RESID

DELTIM = DELTA_GO

Then after the mean conic partial subfunction has executed, the result is stored.

PHI_REND_PATCH = $\underline{\Phi}$_MC

The rendezvous radar range measurement partial vector is computed with the following equations.

$\underline{R}$_RHO = $\underline{R}$_TV_RESID-$\underline{R}$_RESID

R_RHO_MAG = |$\underline{R}$_RHO|

$\underline{I}$ RHO = $\underline{R}$_RHO/R_RHO_MAG

$$B_{1 \text{ to } 6} = -(\text{PHI\_PATCH}_{1 \text{ to } 3,\ 1 \text{ to } 6})^T\ \underline{I}\text{ RHO}$$

$$B_{10 \text{ to } 12} = \text{PHI\_REND\_PATCH}^T_{1 \text{ to } 3,\ 1 \text{ to } 3}\ \underline{I}\text{ RHO}$$

$$B_{18} = 1.0$$

The residual is then calculated.

$$\text{Q\_PRIME} = \text{R\_RHO\_MAG} + \text{SENSOR\_BIAS}_3$$

DELQ = Q_RR_RNG-Q_PRIME

Finally the filter gain variance for the measurement is computed.

$$\text{VAR} = (\text{SIG\_RR\_RNG} + \text{SLOPE\_SIG\_RR\_RNG R\_RHO\_MAG})^2$$

If VAR is less than a premission determined number then VAR is set equal to that number.

B. Interface Requirements

The input and output variables for the rendezvous radar range

measurement subfunction are given in tables 4.3.2.7.1-1 and 4.3.2.7.1-2.

C. Processing Requirements

This subfunction shall be performed after the state and covariance propagation, at the basic filter rate. This subfunction is performed as long as rendezvous radar range measurements are being processed.

D. Constraints

None.

E. Supplementary Information

A suggested implementation of this subfunction is shown in flow charts RR DOT_NAV, REND_NAV_INTERP, ONORBIT_SV_INTERP, and MEAN_CONIC_PARTIAL_TRANSITION_MATRIX_6X6 in Appendix B.

TABLE 4.3.2.7.1-1. - Rendezvous Radar Range Measurement Input Parameters

DESCRIPTION	SYMBOL	INPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	SAMPLE RATE
Filter current shuttle position vector in M50 coordinates	R_FILT	State Propagation	V	DP		ft	Filter rate
Filter current shuttle velocity vector in M50 coordinates	V_FILT	State Propagation	V	DP		ft/sec	Filter rate
Time tag for latest navigation cycle	T_CURRENT_FILT	State Propagation	V	DP		sec	Filter rate
Difference between accumulated sensed IMU readings on present cycle and previous cycle	DV_FILT	State Propagation	V	DP		ft/sec	Filter rate
The time interval of the last state and covariance propagation	DT_FILT	State Propagation	F	DP		sec	Filter rate
Position vector of the shuttle at the end of the last filter cycle	R_LAST	State Propagation	V	DP		ft	Filter rate
Velocity vector of the shuttle at the end of the last filter cycle	V_LAST	State Propagation	V	DP		ft/sec	Filter rate
Filter estimated target position at the end of the last filter cycle	R_TV_LAST	State Propagation	V	DP		ft	Filter rate

TABLE 4.3.2.7.1-1. (continued) - Rendezvous Radar Range Measurement Input Parameters

DESCRIPTION	SYMBOL	INPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	SAMPLE RATE
Filter estimated target position vector at the end of the last filter cycle	V_TV_LAST	State Propagation	V	DP		ft/sec	Filter rate
Current target position vector in M50 coordinates	R_TV	State Propagation	V	DP		ft	Filter rate
Current target velocity vector in M50 coordinates	V_TV	State Propagation	V	DP		ft/sec	Filter rate
Target's gravity vector at the end of the last integration interval	G_TV	State Propagation	V	DP		ft/sec^2	Filter rate
Time tag for the rendezvous radar range and range rate measurements	T_REND_RADAR	external sensor data snap	F	DP		sec	Filter rate
Rendezvous radar range measurement	Q_RR_RNG	external sensor data snap	F	DP		ft	Filter rate
A discrete indicating the degree of the acceleration model used	IGD	state propagation	D				Filter rate
A discrete indicating the order of the acceleration model to be used	IGO	state propagation	D				Filter rate

TABLE 4.3.2.7.1-1. (continued) - Rendezvous Radar Range Measurement Input Parameters

DESCRIPTION	SYMBOL	INPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	SAMPLE RATE
A flag indicating whether drag is to be modeled in the acceleration calculation	IDM	state propagation	D		0,1		Filter rate
A flag indicating whether venting is to be modeled in the acceleration equations	IVM	state propagation	D		0,1		Filter rate
A discrete indicating the type of atmosphere modeling to be used in the acceleration calculations	IATM	state propagation	D				Filter rate
Total orbiter acceleration	$\underline{TOT\_ACC}$	state propagation	V	DP		ft/sec^2	Filter rate
The filter estimated sensor bias	$\underline{SENSOR\_BIAS}$	state propagation	V	DP		VARY	Filter rate
Gravitational constant of the earth	EARTH_MU	premission load	F	DP		$(ft^3/sec)^2$	Filter rate
Square root of EARTH_MU	SQR_EMU	premission load	F	DP		ft^3/sec	Filter rate
Tolerance for succesive iterations in the solution of Kepler's equation	EPS_KEP	premission load	F	DP		rad	Filter rate
Maximum time skew between the measurement time and the time of the nav cycle before the state is interpolated to the measurement time	EPS_TIME	premission load	V	DP		sec	Filter rate

TABLE 4.3.2.7.1-1. (continued) - Rendezvous Radar Range Measurement Input Parameters

DESCRIPTION	SYMBOL	INPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	SAMPLE RATE
Flag indicating processable data from the rendezvous radar range sensor	RNG_DATA_GOOD	external sensor data snap	D		ON OFF		Filter rate
One sigma statistic of rendezvous radar range measurement	SIG_RR_RNG	premission load	F	DP		ft	Filter rate
Rate of change of rendezvous radar range statistic W.R.T. range	SLOPE_SIG_RR_RNG	premission load	F	DP		unitless	Filter rate
Minimum value for computation of rendezvous radar range variance	VAR_RR_RNG_MIN	premission load	F	DP		ft^2	Filter rate
Acceleration constants		*					

* Given in I-load requirements section 4.8

TABLE 4.3.2.7.1-2. - Rendezyous Radar Range Measurement Output Parameters

DESCRIPTION	SYMBOL	OUTPUT DESTINATION	TYPE	PRECISION	RANGE	UNITS	COMPUTATION RATE
The navigation filter measurement residual	DELQ	Measurement incorporation	F	DP		ft	Filter rate
The measurement partials	$\underline{B}$	Measurement incorporation	V	DP		VARY	Filter rate
The general filter gain variance for the sensors	VAR	Measurement incorporation	F	DP		VARY	Filter rate

4.3.2.7.2 Rendezvous radar range rate. The rendezvous radar range rate measurement subfunction computes an estimated range rate of the orbiter with respect to the target vehicle, the range rate measurement residual, and the range rate measurement partial vector, and selects the proper variance to model the uncorrelated instrument error. This subfunction is performed only when rendezvous radar range rate data are indicated valid.

A. Detailed Requirements. A description of the symbols used in the following equations may be found in tables 4.3.2.7.2-1 and 4.3.2.7.2-2.

First the orbiter and target states are interpolated to measurement time and the orbiter and target transition matrices are calculated as described in section 4.3.2.7.1 for the range measurement with SENSOR_ID equal to 2 instead of 1.

The rendezvous radar range rate partial vector is computed with the following equations:

$$\underline{U}\text{\_RDOT} = (\underline{V}\text{\_TV\_RESID} - \underline{V}\text{\_RESID})\ \ \text{RRHO\_MAG}$$

$$B_{1\text{ to }3} = \underline{I}\text{\_RHO X } (\underline{I}\text{\_RHO X } \underline{U}\text{\_RDOT})$$

$$B_{10\text{ to }12} = -B_{1\text{ to }3}$$

$$B_{4\text{ to }6} = -\underline{I}\text{\_RHO}$$

$$B_{10\text{ to }15} = -B_{4\text{ to }6}$$

$$B_{10\text{ to }15} = \underline{\text{PHI\_REND\_PATCH}}^{T}\ B_{10\text{ to }15}$$

The residual is then calculated:

$$Q\_PRIME = \underline{R}\_RHO \cdot \underline{U}\_RDOT + SENSOR - BIAS_4$$

$$DELQ = Q\_RR\_RNG\_DOT - Q\_PRIME$$

Finally the filter gain variance for the measurement is defined:

$$VAR = VAR\_RANGE\_DOT$$

B. Interface Requirements. The input and output variables for the rendezvous radar range rate measurement subfunction are given in tables 4.3.2.7.2.-1 and 4.3.2.7.2-2.

C. Processing Requirements. This subfunction shall be performed after the state and covariance propagation, at the basic filter rate. This subfunction is performed as long as rendezvous radar range rate measurements are being processed.

D. Constraints. None.

E. Supplementary Information. A suggested implementation of this subfunction is shown in flow charts RR_DOT_NAV, REND_NAV_INTERP, ONORBIT_SV_INTERP, and MEAN_CONIC_PARTIAL_TRANSITION_MATRIX_6X6 in Appendix B.

TABLE 4.3.2.7.2-1 - RENDEZVOUS RADAR RANGE RATE MEASUREMENT INPUT PARAMETERS

DESCRIPTION	SYMBOL	INPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	SAMPLE RATE
Filter current shuttle position vector in M50 coordinates	R_FILT	state propagation	V	DP	—	ft	filter rate
Filter current shuttle velocity vector in M50 coordinates	V_FILT	state propagation	V	DP	—	ft/sec	filter rate
Time tag for latest navigation cycle	T_CURRENT_FILT	state propagation	V	DP	—	sec	filter rate
Difference between accumulated sensed IMU readings on present cycle and previous cycle	DV_FILT	state propagation	V	DP	—	ft/sec	filter rate
The time interval of the last state and covariance propagation	DT_FILT	state propagation	F	DP	—	sec	filter rate
Position vector of the shuttle at the end of the last filter cycle	R_LAST	state propagation	V	DP	—	ft	filter rate
Velocity vector of the shuttle at the end of the last filter cycle	V_LAST	state propagation	V	DP	—	ft/sec	filter rate

TABLE 4.3.2.7.2-1 - (continued) RENDEZVOUS RADAR RANGE RATE MEASUREMENT INPUT PARAMETERS

DESCRIPTION	SYMBOL	INPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	SAMPLE RATE
Filter estimated target position at the end of the last filter cycle	R_TV_LAST	state propagation	V	DP	_	ft	filter rate
Filter estimated target position vector at the end of the last filter cycle	V_TV_LAST	state propagation	V	DP	_	ft/sec	filter rate
Current target position vector in M50 coordinates	R_TV	state propagation	V	DP	_	ft	filter rate
Current target velocity vector in M50 coordinates	V_TV	state propagation	V	DP	_	ft/sec	filter rate
Target's gravity vector at the end of the last integration interval	G_TV	state propagation	V	DP	_	ft/sec^2	filter rate
A discrete indicating the degree of the acceleration model used.	IGD	state propagation	D	_	_	_	filter rate
A discrete indicating the order of the acceleration model to be used.	IGO	state propagation	D	_	_	_	filter rate

C.4

TABLE 4.3.2.7.2-1 - (continued) RENDEZVOUS RADAR RANGE RATE MEASUREMENT INPUT PARAMETERS

DESCRIPTION	SYMBOL	INPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	SAMPLE RATE
A flag indicating whether drag is to be modeled in the acceleration calculation.	IDM	state propagation	D	—	0-1	—	filter rate
A flag indicating whether venting is to be modeled in the acceleration equators	IVM	state propagation	D	—	0-1	—	filter rate
A discrete indicating the type of atmosphere modeling to be used in the acceleration calculations	IATM	state propagation	D	—	—	—	filter rate
Total orbiter acceleration	TOT_ACC	state propagation	V	DP	—	ft/sec^2	filter rate
The filter estimated sensor bias	SENSOR_BIAS	state propagation	V (4)	DP	—	vary	filter rate
Gravitational constant of earth	EARTH_MU	premission load	F	DP		ft^3/sec	filter rate
Square root of EARTH_MU	SQR_EMU	premission load	F	DP		ft^3/sec	filter rate
Tolerance for successive iterations in the solution of Kepler's equation	EPS_KEP	premission load	F	DP		rad	filter rate

ORIGINAL PAGE IS OF POOR QUALITY

TABLE 4.3.2.7.2-1 - (continued) RENDEZVOUS RADAR RANGE RATE MEASUREMENT INPUT PARAMETERS

DESCRIPTION	SYMBOL	INPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	SAMPLE RATE
Maximum time skew between the measurement time and the time of the nav cycle before the state is interpolated to the measurement time.	EPS_TIME	premission load	V	—	—	sec	filter rate
Flag indicating processable data from the rendezvous radar range rate sensor	RDOT_DATA_GOOD	Sensor Data Snap	F	DP	—	—	filter rate
Variance of rendezvous radar range rate sensor measurement	VAR_RANGE_DOT	premission load	F	DP	—	—	filter rate
Rendezvous radar range rate measurement	Q_RR_DOT	Sensor Data Snap	F	DP	—	—	filter rate
Acceleration constants		*					

* Given in I-load requirements, section 4.8

TABLE 4.3.2.7.2-2 - RENDEZVOUS RADAR RANGE RATE OUTPUT PARAMETERS

DESCRIPTION	SYMBOL	OUTPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	COMPUTATION RATE
The navigation filter measurement residual	DELQ	Measurement Incorporation	F	DP	—	ft	filter rate
The measurement partials	$\underline{B}$	Measurement Incorporation	V	DP	—	vary	filter rate
The general filter gain variance for the sensors	VAR	Measurement Incorporation	F	DP	—	vary	filter rate

4.3.2.7.3 Rendezvous Radar Shaft Angle

The rendezvous radar shaft angle measurement subfunction computes an estimated shaft angle, the angle measurement residual, and selects the proper variance to model the uncorrelated instrument error.

A. Detailed Requirements

A description of the symbols used in the following equations may be found in tables 4.3.7.3-1 and 4.3.2.7.3-2. This subfunction is exercised only when rendezvous radar angle data are selected for processing and are valid.

First, the orbiter and target states are interpolated to the time of the measurement and the orbiter and target transition matrices are calculated as described in section 4.3.2.7.1 where

DELTAT_GO = T_CURRENT_FILT-T_REND_RADAR

The partials are computed by the angle measurement partials subfunction as described in section 4.2.6. The parameters in that common subfunction must be given the following values prior to execution:

M_M50_TO_SENSOR = M_BODY_TO_RR

M_M50_TO_BODY_RR

$\underline{I}$_N = $\text{M\_M50\_TO\_SENSOR}_{3,\ 1\ \text{to}\ 3}$

Calculation of the partial vector is completed by setting the appropriate value in the bias slot of that vector.

$B_1 = 1.0$

The residual is calculated as follows.

$\underline{U}\_M$ = M_M50_TO_SENSOR UNIT($\underline{R}\_RHO$)

SHFT = ARCTAN(U_M_2/U_M_1) + $BIAS\_SENSOR_2$

DELQ = Q_RR_SHFT-SHFT

where $\underline{R}\_RHO$ is defined by the partial calculations. Finally the appropriate variance for the COAS horizontal angle is assigned.

VAR = VAR_SHFT

B. <u>Interface Requirements</u>

The input and output variables for the rendezvous radar shaft angle subfunction are given in tables 4.3.2.7.3-1 and 4.3.2.7.3-2.

C. <u>Processing Requirements</u>

This subfunction shall be performed after the state and covariance propagation, at the basic filter rate. This subfunction is performed as long as rendezvous radar angle measurements are being processed.

D. <u>Constraints</u>

None.

E. <u>Supplementary Information</u>

A suggested implementation of this subfunction is shown in flowcharts NAV_RENDEZVOUS, RR_ANGLE_NAV, REND_NAV_INTERP, ONORBIT_SV_INTERP and MEAN_CONIC_PARTIAL_TRANSITION_MATRIX_6X6 in Appendix B.

TABLE 4.3.2.7.3-1 - Rendezyous Radar Shaft Angle Measurement Input Parameters

DESCRIPTION	SYMBOL	INPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	SAMPLE RATE
Filter current shuttle position vector in M50 coordinates	R_FILT	state propagation	V	DP		ft	Filter rate
Filter current shuttle velocity vector in M50 coordinates	V_FILT	state propagation	V	DP		ft/sec	Filter rate
Time tag for latest navigation cycle	T_CURRENT_FILT	state propagation	V	DP		sec	Filter rate
Difference between accumulated sensed IMU readings on present cycle and previous cycle	DV_FILT	state propagation	V	DP		ft/sec	Filter rate
The time interval of the last state and covariance propagation	DT_FILT	state propagation	F	DP		sec	Filter rate
Position vector of the shuttle at the end of the last filter cycle	R_LAST	state propagation	V	DP		ft	Filter rate
Velocity vector of the shuttle at the end of the last filter cycle	V_LAST	state propagation	V	DP		ft/sec	Filter rate
Filter estimated target position at the end of the last filter cycle	R_TV_LAST	state propagation	V	DP		ft	Filter rate

TABLE 4.3.2.7.3-1 - (continued) - Rendezyous Radar Shaft Angle Measurement Input Parameters

DESCRIPTION	SYMBOL	INPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	SAMPLE RATE
Filter estimated target position vector at the end of the last filter cycle	V_TV_LAST	state propagation	V	DP		ft/sec	Filter rate
Current target position vector in M50 coordinates	R_TV	state propagation	V	DP		ft	Filter rate
Current target velocity vector in M50 coordinates	V_TV	state propagation	V	DP		ft/sec	Filter rate
Target's gravity vector at the end of the last integration interval	G_TV	state propagation	V	DP		ft/sec^2	Filter rate
A discrete indicating the degree of the acceleration model used	IGD	state propagation	D				Filter rate
A discrete indicating the order of the acceleration model to be used	IGO	state propagation	D				Filter rate
A flag indicating whether drag is to be modeled in the acceleration calculation	IDM	state propagation	D		0,1		Filter rate
A flag indicating whether venting is to be modeled in the acceleration equations	IVM	state propagation	D		0,1		Filter rate

TABLE 4.3.2.7.3-1 - (continued) - Rendezvous Radar Shaft Angle Measurement Input Parameters

DESCRIPTION	SYMBOL	INPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	SAMPLE RATE
A discrete indicating the type of atmosphere modeling to be used in the acceleration calculations	IATM	state propagation	D				Filter rate
Total orbiter accelerations	TOT_ACC	state propagation	V	DP		ft/sec^2	Filter rate
The filter estimated sensor bias	SENSOR_BIAS	state propagation	V	DP		VARY	Filter rate
Gravitational constant of the earth	EARTH_MU	premission load	F	DP		$(ft^3/sec)^2$	Filter rate
Square root of EARTH_MU	SQR_EMU	premission load	F	DP		ft^3/sec	Filter rate
Tolerance for succesive iterations in the solution of Kepler's equation	EPS_KEP	premission load	F	DP		rad	Filter rate
Maximum time skew between the measurement time and the time of the nav cycle before the state is interpolated to the measurement time	EPS_TIME	premission load	F	DP		sec	Filter rate
Flag indicating processable data from the rendezvous radar angle sensor	RR_ANGLE_DATA_GOOD	external sensor data snap	D		ON,OFF		Filter rate

TABLE 4.3.2.7.3-1 - (continued) - Rendezvous Radar Shaft Angle Measurement Input Parameters

DESCRIPTION	SYMBOL	INPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	SAMPLE RATE
Variance of the rendezvous radar shaft measurement	VAR_SHFT	premission load	F	DP		rad^2	Filter rate
Time tag for the rendezvous radar measurements	T_REND_RADAR	external sensor data snap	F	DP		sec	Filter rate
The rendezvous radar shaft measurement	Q_RR_SHFT	external sensor data snap	F	DP		rad	Filter rate
M50 to body transformation matrix at the time the rendezvous radar data was snapped	M_M50_TO_BODY_RR	external sensor data snap	M	DP			Filter rate
Body to rendezvous radar transformation matrix	M_BODY_TO_RR	premission load	M	DP			Filter rate
Acceleration constants		*					

* Given in I-load requirements section 4.8

ORIGINAL PAGE IS OF POOR QUALITY

TABLE 4.3.2.7.3-2. - Rendezvous Radar Shaft Angle Measurement Output Parameters

DESCRIPTION	SYMBOL	OUTPUT DESTINATION	TYPE	PRECISION	RANGE	UNITS	COMPUTATION RATE
The navigation filter measurement residual	DELQ	Measurement Incorporation	F	DP		ft	Filter rate
The measurement partials	$\underline{B}$	Measurement Incorporation	V	DP		VARY	Filter rate
The general filter gain variance for the sensors	VAR	Measurement Incorporation	F	DP		VARY	Filter rate

4.3.2.7.4 Rendezvous Radar Trunion Angle

The rendezvous radar trunion angle measurement subfunction computes an estimated trunion angle, the angle measurement residual, and the trunion angle partial vector, and selects the proper variance to model the uncorrelated instrument error.

A. Detailed Requirements

A description of the symbols used in the following equations may be found in tables 4.3.2.7.4-1 and 4.3.2.7.4-2. This subfunction is exercised only when rendezvous radar angle data are selected for processing and are valid.

First, the orbiter and target states are interpolated to the time of the measurement and the orbiter and target transition matrices are calculated as described in section 4.3.2.7.1 where

DELTAT_GO = T_CURRENT_FILT-T_REND_RADAR

The partials are computed by the angle measurement partials subfunction as described in section 4.2.6. The parameters in that common subfunction must be given the following values prior to execution:

M_M50_TO_SENSOR = M_BODY_TO_RR
M_M50_TO_BODY_RR

and

I_N = UNIT (R_TV_RESID_R_RESID) X M_M50_TO_SENSOR$_{3,\ 1 \text{ to } 3}$

where $\underline{R}$_TV_RESID and $\underline{R}$_RESID are the result of the interpolation of the target and the orbiter respectively.

Calculation of the partial vector, is completed by setting the appropriate value in the bias slot of that vector.

$$B_{17} = 1.0$$

The residual is calculated as follows.

$$\underline{U}\_M = M\_M50\_TO\_SENSOR \;\; UNIT\ (\underline{R}\_RHO)$$

$$TRUN = ARCSIN\ (U\_M_3) + BIAS\_SENSOR_2$$

$$DELQ = Q\_RR\_TRUN-TRUN$$

where $\underline{R}$_RHO is defined by the partial calculations.

Finally the appropriate variance for the trunion angle is assigned.

$$VAR = VAR\_TRUN$$

B. Interface Requirements

The input and output variables for the rendezvous radar trunion angle subfunction are given in tables 4.3.2.7.4-1 and 4.3.2.7.4-2.

C. Processing Requirements

This subfunction shall be performed after the state and covariance propagation, at the basic filter rate. This subfunction is performed as long as rendezvous radar angle measurements are being processed.

D. Constraints

None.

E. Supplementary Information

A suggested implementation of this subfunction is shown in flow charts NAV_RENDEZVOUS, RR_ANGLE_NAV, REND_NAV_INTERP, ONORBIT_SV_INTERP and MEAN_CONIC_PARTIAL_TRANSITION_MATRIX_6X6 in Appendix B.

Table 4.3.2.7.4-1. - Rendezvous Radar Trunion Angle Measurement Input Parameters

DESCRIPTION	SYMBOL	INPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	SAMPLE RATE
Filter current shuttle position vector in M50 coordinates	R_FILT	state propagation	V	DP		ft	Filter rate
Filter current shuttle velocity vector in M50 coordinates	V_FILT	state propagation	V	DP		ft/sec	Filter rate
Time tag for latest navigation cycle	T_CURRENT_FILT	state propagation	V	DP		sec	Filter rate
Difference between accumulated sensed IMU readings on present cycle and previous cycle	DV_FILT	state propagation	V	DP		ft/sec	Filter rate
The time interval of the last, state and covariance propagation	DT_FILT	state propagation	F	DP		sec	Filter rate
Position vector of the shuttle at the end of the last filter cycle	R_LAST	state propagation	V	DP		ft	Filter rate
Velocity vector of the shuttle at the end of the last filter cycle	V_LAST	state propagation	V	DP		ft/sec	Filter rate
Filter estimated target position at the end of the last filter cycle	R_TV_LAST	state propagation	V	DP		ft	Filter rate

Table 4.3.2.7.4-1. (continued) - Rendezvous Radar Trunion Angle Measurement Input Parameters

DESCRIPTION	SYMBOL	INPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	SAMPLE RATE
Filter estimated target position vector at the end of the last filter cycle	V_TV_LAST	state propagation	V	DP		ft/sec	Filter rate
Current target position vector in M50 coordinates	R_TV	state propagation	V	DP		ft	Filter rate
Current target velocity vector in M50 coordinates	V_TV	state propagation	V	DP		ft/sec	Filter rate
Target's gravity vector at the end of the last integration interval	G_TV	state propagation	V	DP		ft/sec^2	Filter rate
A discrete indicating the degree of the acceleration model used	IGD	state propagation	D				Filter rate
A discrete indicating the order of the acceleration model to be used	IGO	state propagation	D				Filter rate
A flag indicating whether drag is to be modeled in the acceleration calculation	IDM	state propagation	D		0,1		Filter rate
A flag indicating whether venting is to be modeled in the acceleration equations	IVM	state propagation	D		0,1		Filter rate

Table 4.3.2.7.4-1. (continued) - Rendezvous Radar Trunion Angle Measurement Input Parameters

DESCRIPTION	SYMBOL	INPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	SAMPLE RATE
A discrete indicating the type of atmosphere modeling to be used in the acceleration calculations	IATM	state propagation	D				Filter rate
Total orbiter acceleration	TOT_ACC	state propagation	V	DP		ft/sec^2	Filter rate
The filter estimated sensor bias	SENSOR_BIAS	state propagation	V	DP		VARY	Filter rate
Gravitational constant of the earth	EARTH_MU	premission load	F	DP		$(ft^3/sec)^2$	Filter rate
Square root of EARTH_MU	SQR_EMU	premission load	F	DP		ft^3/sec	Filter rate
Tolerance for succesive iterations in the solution of Kepler's equation	EPS_KEP	premission load	F	DP		rad	Filter rate
Maximum time skew between the measurement time and the time of the nav cycle before the state is interpolated to the measurement time	EPS_TIME	premission load	V	DP		sec	Filter rate
Flag indicating processable data from the rendezvous radar angle sensor	RR_ANGLE_DATA_GOOD	external sensor data snap	D		ON, OFF		Filter rate

Table 4.3.2.7.4-1. (continued) - Rendezvous Radar Trunion Angle Measurement Input Parameters

DESCRIPTION	SYMBOL	INPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	SAMPLE RATE
Variance of the rendezvous radar trunion measurement	VAR_TRUN	premission load	F	DP		rad^2	Filter rate
Time tag for the rendezvous radar measurements	T_REND_RADAR	external sensor data snap	F	DP		sec	Filter rate
The rendezvous radar trunion measurement	Q_RR_TRUN	external sensor data snap	F	DP		rad	Filter rate
M50 to body transformation matrix at the time the rendezvous radar data was snapped	M_M50_TO_BODY_RR	external sensor data snap	M	DP			Filter rate
Body to rendezvous radar transformation matrix	M_BODY_TO_RR	Premission load	M	DP			Filter rate
Acceleration constants		*					

* Given in I-load requirements section 4.8

Table 4.3.2.7.4-2. - Rendezvous Radar Trunion Angle Measurement Output Parameters

DESCRIPTION	SYMBOL	OUTPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	COMPUTATION RATE
The navigation filter measurement residual	DELQ	Measurement Incorporation	F	DP	—	ft	Filter rate
The measurement partials	$\underline{B}$	Measurement Incorporation	V	DP		VARY	Filter rate
The general filter gain variance for the sensors	VAR	Measurement Incorporation	F	DP		VARY	Filter rate

4.3.2.7.5 - Startracker horizontal angle. The startracker horizontal angle measurement subfunction computes an estimated horizontal startracker angle, the angle measurement residual, and the horizontal angle partials, and selects the proper variance to model the uncorrelated instrument error.

A. Detailed Requirements. A description of the symbols used in the following equations may be found in tables 4.3.2.7.5-1 and 4.3.2.7.5-2. This subfunction is exercised only when startracker data are selected are valid.

First, the orbiter and target states are interpolated to the time of the measurement. The partials are computed by the angle measurement and the orbiter and target transition matrices are calculated as described in section 4.3.2.7.1 where

DELTAT_GO = T_CURRENT_FILT-T_STAR_TRACKER

The partials are computed by the angle measurement partials subfunction as described in section 4.2.6. The parameters in that common subfunction must be given the following values prior to execution:

$$\mathrm{M\_M50\_TO\_SENSOR} = \mathrm{M\_BODY\_TO\_ST}_{\mathrm{N\_ST\_IN\_USE}}\ \mathrm{M\_M50\_TO\_BODY\_ST}$$

$$\underline{\mathrm{I}}\mathrm{\_N} = \mathrm{M\_M50\_TO\_SENSOR}_{1,1\ \mathrm{to}\ 3}$$

Calculation of the partials is completed by setting the appropriate value in the bias slot of the partial vector.

$$B_{17} = 1.0$$

The residual is calculated as follows:

$$\underline{U\_M} = M\_M50\_TO\_SENSOR \ \ UNIT(\underline{R\_RHO})$$

$$HORIZ\_ = ARCTAN\ (UM_2 / UM_3) + BIAS\_SENSOR_2$$

$$DELQ = Q\_ST\_HORIZ - HORIZ$$

where R_RHO is defined by the partial calculation. Finally the appropriate variance for the startrack horizontal angle is assigned

$$VAR = VAR\_ST\_HORIZ$$

B. Interface Requirements. The input and output variables for the startracker horizontal angle subfunction are given in tables 4.3.2.7.5-1 and 4.3.2.7.5-2.

C. Processing Requirements. This subfunction shall be performed after the state and covariance propagation, at the basic filter rate. This subfunction is performed as long as startracker measurements are being processed.

D. Constraints. None.

E. Supplementary Information. A suggested implementation of this subfunction is shown in flowchart NAV_RENDEZVOUS, ANGLE_NAV, REND_NAV_INTERP, ONORBIT_SV_INTERP, and MEAN_CONIC_PARTIAL_TRANSITION_MATRIX_6 X 6 in Appendix B.

TABLE 4.3.2.7.5.-1 - STARTRACKER HORIZONTAL ANGLE MEASUREMENT INPUT PARAMETERS

DESCRIPTION	SYMBOL	INPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	SAMPLE RATE
Filter current shuttle position vector in M50 coordinates	R_FILT	state propagation	V	DP	-	ft	filter rate
Filter current shuttle velocity vector in M50 coordinates	V_FILT	state propagation	V	DP	-	ft/sec	filter rate
Time tag for latest navigation cycles	T_CURRENT_FILT	state propagation	V	DP	-	sec	filter rate
Difference between accumulated sensed IMU readings on present cycle and previous cycle	DV_FILT	state propagation	V	DP	-	ft/sec	filter rate
The time interval of the last state and covariance propagation	DT_FILT	state propagation	F	DP	-	sec	filter rate
Position vector of the shuttle at the end of the last filter cycle	R_LAST	state propagation	V	DP	-	ft	filter rate
Velocity vector of the shuttle at the end of the last filter cycle	V_LAST	state propagation	V	DP	-	ft/sec	filter rate

TABLE 4.3.2.7.5-1 - (Continued) STARTRACKER HORIZONTAL ANGLE MEASUREMENT INPUT PARAMETERS

DESCRIPTION	SYMBOL	INPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	SAMPLE RATE
Filter estimated target position at the end of the last filter cycle	R_TV_LAST	state propagation	V	DP	—	ft	filter rate
Filter estimated target position vector at the end of the last filter cycle	V_TV_LAST	state propagation	V	DP	—	ft/sec	filter rate
Current target position vector in M50 coordinates	R_TV	state propagation	V	DP	—	ft	filter rate
Current target velocity vector in M50 coordinates	V_TV	state propagation	V	DP	—	ft/sec	filter rate
Target's gravity vector at the end of the last integration interval	G_TV	state propagation	V	DP	—	ft/sec^2	filter rate
A discrete indicating degree of the acceleration model used.	IGD	state propagation	D	—	—	—	filter rate
A discrete indicating the order of the acceleration model to be used.	IGO	state propagation	D	—	—	—	filter rate

TABLE 4.3.2.7.5-1 - (Continued) STARTRACKER HORIZONTAL ANGLE MEASUREMENT INPUT PARAMETERS

DESCRIPTION	SYMBOL	INPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	SAMPLE RATE
A flag indicating whether drag is to be modeled in the acceleration calculation	IDM	state propagation	D	—	0-1	—	filter rate
A flag indicating whether venting is to be modeled in the acceleration equations	IVM	state propagation	D	—	0-1	—	filter rate
A discrete indicating the type of atmosphere modeling to be used in the acceleration calculations	IATM	state propagation	D	—	—	—	filter rate
Total orbiter acceleration	TOT_ACC	state propagation	V	DP	—	ft/sec^2	filter rate
The filter estimated sensor bias	SENSOR_BIAS	state propagation	V	DP	—	vary	filter rate
Square root of EARTH_MU	EARTH_MU	premission load	F	DD	—	ft^3/sec^2	filter rate
Tolerance for successive iterations in the solution of Kepler's equation	EPS_KEP	premission load	F	DP	—	rad	filter rate

TABLE 4.3.2.7.5 -1 - (Continued) STARTRACKER HORIZONTAL ANGLE MEASUREMENT INPUT PARAMETERS

DESCRIPTION	SYMBOL	INPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	SAMPLE RATE
Maximum time skew between the measurement time and the time of the nav cycle before the state is interpolated to the measurement time.	EPS_TIME	premission load	V	DP	_	sec	filter rate
Flag indicating processable data from the startracker measurement	ST_DATA_GOOD	external sensor data snap	D	_	ON/OFF	_	filter rate
Variance of startracker horizontal measurement	VAR_ST_HORIZ	premission load	F	DP	_	rad^2	filter rate
Time tag for the startracker measurements	T_STAR_TRACKER	external data snap	F	DP	_	sec	filter rate
The startracker horizontal measurement	Q_ST_HORIZ	external data snap	F	DP	_	rad	filter rate
M50 to body transformation matrix at the time the startracker data was snapped	M_M50_TO_BODY_ST	external data snap	M	DP	_	_	filter rate

TABLE 4.3.2.7.5-1 - (Continued) STARTRACKER HORIZONTAL ANGLE MEASUREMENT INPUT PARAMETERS

DESCRIPTION	SYMBOL	INPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	SAMPLE RATE
Body to startracker transformation matrix	M_BODY_TO_ST	Premission load	M	DP	_	_	filter rate
Index indicating which startracker is being used	N_ST_IN_USE	external data snap	D	_	_	_	filter rate
Acceleration constants		*					

* Given in I-load requirements, section 4.8.

TABLE 4.3.2.7.1 - 2 - RENDEZVOUS RADAR RANGE MEASUREMENT OUTPUT PARAMETERS

DESCRIPTION	SYMBOL	OUTPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	COMPUTATION RATE
The navigation filter measurement residual	DELQ	Measurement Incorporation	F	DP	—	ft	filter rate
The measurement partials	$\underline{B}$	Measurement Incorporation	V(19)	DP	—	vary	filter rate
The general filter gain variance for the sensors	VAR	Measurement Incorporation	F	DP	—	vary	filter rate

4.3.2.7.6 Startracker Vertical Angle

The startracker vertical angle measurement subfunction computes an estimated vertical startracker angle, the angle measurement residual, and the vertical angle partials, and selects the proper variance to model the uncorrelated instrument error.

A. Detailed Requirements

A description of the symbols used in the following equations may be found in tables 4.3.2.7.6-1 and 4.3.2.7.6-2. This subfunction is exercised only when startracker data are selected and are valid.

First, the orbiter and target states are interpolated to the time of the measurement and the orbiter and target transition matrices are calculated as described in section 4.3.2.7.1 where

DELTAT_GO = T_CURRENT_FILT_T_STAR_TRACKER

The partials are computed by the angle measurement partials subfunction as described in section 4.2.6. The parameters in that common subfunction must be given the following values prior to execution.

$$\text{M\_M50\_TO\_SENSOR} = \text{M\_BODY\_TO\_ST}_{\text{N\_ST\_IN\_USE}}\text{M\_M50\_TO\_BODY\_ST}$$

$$\underline{\text{I}}\text{\_N} = \text{M\_M50\_TO\_SENSOR}_{2,\ 1\ \text{to}\ 3}$$

Calculation of the partials is completed by setting the appropriate value in the bias slot of the partial vector.

$B_{16} = 1.0$

The residual is calculated as follows.

$$\underline{U}\_M = M\_M50\_TO\_SENSOR \;\; UNIT(\underline{R}\_RHO)$$

$$VERT = ARCTAN\ (U\_M_1/U\_M_3) + BIAS\_SENSOR_1$$

$$DELQ = Q\_ST\_VERT-VERT$$

where $\underline{R}\_RHO$ is defined by the partial calculation. Finally the appropriate variance for the startracker vertical angle. is assigned

$$VAR = VAR\_ST\_VERT$$

B. Interface Requirements

The input and output variables for the startracker vertical angle subfunction are given in tables 4.3.2.7.6-1 and 4.3.2.7.6-2.

C. Processing Requirements

This subfunction shall be performed after the state and covariance propagation, at the basic filter rate. This subfunction is performed as long as startracker measurements are being processed.

D. Constraints

None.

E. Supplementary Information

A suggested implementation of this subfunction is shown in flowcharts NAV_RENDEZVOUS, ANGLE_NAV, REND_NAV_INTERP, ONORBIT_SV_INTERP, and MEAN_CONIC_PARTIAL_TRANSITION_MATRIX_6X6 in Appendix B.

TABLE 4.3.2.7.6-1 - Startracker Vertical Angle Measurement Input Parameters

DESCRIPTION	SYMBOL	INPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	SAMPLE RATE
Filter current shuttle position vector in M50 coordinates	R_FILT	state propagation	V	DP		ft	Filter rate
Filter current shuttle velocity vector in M50 coordinates	V_FILT	state propagation	V	DP		ft/sec	Filter rate
Time tag for latest navigation cycle	T_CURRENT_FILT	state propagation	V	DP		sec	Filter rate
Difference between accumulated sensed IMU readings on present cycle and previous cycle	DV_FILT	state propagation	V	DP		ft/sec	Filter rate
The time interval of the last, state and covariance propagation	DT_FILT	state propagation	F	DP		sec	Filter rate
Position vector of the shuttle at the end of the last filter cycle	R_LAST	state propagation	V	DP		ft	Filter rate
Velocity vector of the shuttle at the end of the last filter cycle	V_LAST	state propagation	V	DP		ft/sec	Filter rate
Filter estimated target position at the end of the last filter cycle	R_TV_LAST	state propagation	V	DP		ft	Filter rate

TABLE 4.3.2.7.6-1 (continued) - Startracker Vertical Angle Measurement Input Parameters

DESCRIPTION	SYMBOL	INPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	SAMPLE RATE
Filter estimated target position vector at the end of the last filter cycle	V_TV_LAST	state propagation	V	DP		ft/sec	Filter rate
Current target position vector in M50 coordinates	R_TV	state propagation	V	DP		ft	Filter rate
Current target velocity vector in M50 coordinates	V_TV	state propagation	V	DP		ft/sec	Filter rate
Target's gravity vector at the end of the last integration interval	G_TV	state propagation	V	DP		ft/sec^2	Filter rate
A discrete indicating the degree of the acceleration model used	IGD	state propagation	D				Filter rate
A discrete indicating the order of the acceleration model to be used	IGO	state propagation	D				Filter rate
A flag indicating whether drag is to be modeled in the acceleration calculation	IDM	state propagation	D		0 1		Filter rate
A flag indicating whether venting is to be modeled in the acceleration equations	IVM	state propagation	D		0 1		Filter rate

TABLE 4.3.2.7.6-1 (continued) - Startracker Vertical Angle Measurement Input Parameters

DESCRIPTION	SYMBOL	INPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	SAMPLE RATE
A discrete indicating the type of atmosphere modeling to be used in the acceleration calculations	IATM	state propagation	D				Filter rate
Total orbiter acceleration	TOT_ACC	state propagation	V	DP		ft/sec^2	Filter rate
The filter estimated sensor bias	SENSOR_BIAS	state propagation	V	DP		VARY	Filter rate
Gravitational constant of the earth	EARTH_MU	premission load	F	DP		$(ft^3/sec)^2$	Filter rate
Square root of EARTH_MU	SQR_EMU	premission load	F	DP		ft^3/sec	Filter rate
Tolerance for succesive iterations in the solution of Kepler's equation	EPS_KEP	premission load	F	DP		rad	Filter rate
Maximum time skew between the measurement time and the time of the nav cycle before the state is interpolated to the measurement time	EPS_TIME	premission load	V	DP		sec	Filter rate
Flag indicating processable data from the startracker measurement	ST_DATA_GOOD	External sensor data snap	D		ON OFF		Filter rate
Variance of startracker vertical measurement	VAR_ST_VERT	premission load	F	DP		rad^2	Filter rate

TABLE 4.3.2.7.6-1 (continued) - Startracker Vertical Angle Measurement Input Parameters

DESCRIPTION	SYMBOL	INPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	SAMPLE RATE
Startracker vertical measurement	Q_ST_VERT	external sensor data snap	F	DP		rad	Filter rate
Time tag for startracker measurement	T_STAR_TRACKER	external sensor data snap	F	DP		sec	Filter rate
M50 to body transformation matrix at the time the startracker data was snapped	M_M50_TO_BODY_ST	premission load	M	DP			Filter rate
Body to startracker transformation matrix	M_BODY_TO_ST	premission load	M	DP			Filter rate
Index indicating which startracker is being used	N_ST_IN_USE	external data snap	D	DP			Filter rate
Acceleration constants		*					

* Given in I-load requirements section 4.8

TABLE 4.3.2.7.6-2 - Startracker Vertical Angle Measurement Output Parameters

DESCRIPTION	SYMBOL	OUTPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	COMPUTATION RATE
The navigation filter measurement residual	DELQ	Measurement Incorporation	F	DP		ft	Filter rate
The measurement partials	$\underline{B}$	Measurement Incorporation	V	DP		VARY	Filter rate
The general filter gain variance for the sensors	VAR	Measurement Incorporation	F	DP		VARY	Filter rate

4.3.2.7.7 COAS Horizontal Angle.

The COAS horizontal angle measurement subfunction computes an estimated horizontal COAS angle, the angle measurement residual, and the horizontal angle partial vector, and selects the proper variance to model the uncorrelated instrument error.

A. Detailed Requirements.

A description of the symbols used in the following equations may be found in tables 4.3..2.7.7-1 and 4.3.2.7.7-2. This subfunction is exercised only when COAS data are selected and are valid.

First, the orbiter and target are interpolated to the time of the measurement and the orbiter and target transition matrices are calculated as described in section 4.3.2.7.1 where

$$\mathrm{DELTAT\_GO} = \mathrm{T\_CURRENT\_FILT} - \mathrm{T\_COAS}$$

The partials are computed by the angle measurement partials subfunction as described in section 4.2.6. The parameters in that common subfunction must be given the following values prior to execution.

$$\mathrm{M\_M50\_TO\_SENSOR} = \mathrm{M\_BODY\_TO\_COAS}_{\mathrm{N\_COAS\_IN\_USE}}$$

$$\underline{\mathrm{I}}\mathrm{\_N} = \mathrm{M\_M50\_TO\_SENSOR}_{1,1\ \mathrm{to}\ 3}$$

Calculation of the partial vector is completed by setting the appropriate value in the bias slot of that vector.

$B_{17} = 1.0$

The residual is calculated as follows.

U_M = M_M50_TO_SENSOR UNIT (R_RHO)

HORIZ = ARCTAN (U_M_2/U_M_3) + $BIAS\_SENSOR_2$

DELQ = Q_COAS_HORIZ-HORIZ

where R_RHO is defined by the partial calculations.

Finally the appropriate variance for the COAS horizontal angle is assigned.

VAR = VAR_COAS_HORIZ

B. Interface Requirements. The input and output variables for the COAS horizontal angle subfunction are given in tables 4.3.2.7.7-1 and 4.3.2.7.7-2.

C. Processing Requirements. This subfunction shall be performed after the state and covariance propagation, at the basic filter rate. This subfunction is performed as long as COAS measurements are being processed.

D. Constraints. None.

E. Supplementary Information. A suggested implementation of this subfunction is shown in flowcharts NAV_RENDEZVOUS, ANGLE_NAV, REND_NAV_INTERP, ONORBIT_SV_INTERP and MEAN_CONIC_PARTIAL_TRANSITION_MATRIX_6X6 in Appendix B.

TABLE 4.3.2.7.7-1 - COAS HORIZONTAL ANGLE MEASUREMENT INPUT PARAMETERS

DESCRIPTION	SYMBOL	INPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	SAMPLE RATE
Filter current shuttle position vector in M50 coordinates	R_FILT	state propagation	V	DP	—	ft	filter rate
Filter current shuttle velocity vector in M50 coordinates	V_FILT	State propagation	V	DP	—	ft/sec	filter rate
Time tag for latest navigation cycle	T_CURRENT_FILT	State propagation	V	DP	—	sec	filter rate
Difference between accumulated sensed IMU readings on present cycle and previous cycle	DV_FILT	State propagation	V	DP	—	ft/sec	filter rate
The time interval of the last state and covariance propagation	DT_FILT	State propagation	F	DP	—	sec	filter rate
Position vector of the shuttle at the end of the last filter cycle	R_LAST	State propagation	V	DP	—	ft	filter rate
Velocity vector of the shuttle at the end of the last filter cycle	V_LAST	State propagation	V	DP	—	ft/sec	filter rate

TABLE 4.3.2.7.7-1 - (continued) COAS HORIZONTAL ANGLE MEASUREMENT INPUT PARAMETERS

DESCRIPTION	SYMBOL	INPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	SAMPLE RATE
Filter estimated target position at the end of the last filter cycle	R_TV_LAST	state propagation	V	DP	—	ft	filter rate
Filter estimated target position vector at the end of the last filter cycle	V_TV_LAST	state propagation	V	DP	—	ft/sec	filter rate
Current target position vector in M50 coordinates	R_TV	state propagation	V	DP	—	ft	filter rate
Current target velocity vector in M50 coordinates	V_TV	state propagation	V	DP	—	ft/sec	filter rate
Target's gravity vector at the end of the last integration interval	G_TV	state propagation	V	DP	—	ft/sec^2	filter rate
A discrete indicating the degree of the acceleration model used.	IGD	state propagation	D	—	—	—	filter rate
A discrete indicating the order of the acceleration model to be used	IGO	state propagation	D	—	—	—	filter rate

TABLE 4.3.2.7.7-1 - (Continued) COAS HORIZONTAL ANGLE MEASUREMENT INPUT PARAMETERS

DESCRIPTION	SYMBOL	INPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	SAMPLE RATE
A flag indicating whether drag is to be modeled in the acceleration calculation	IDM	state propagation	D	_	0-1	_	filter rate
A flag indicating whether venting is to be modeled in the acceleration equations	IVM	state propagation	D	_	0-1	_	filter rate
A discrete indicating the type of atmosphere modeling to be used in the acceleration calculation	IATM	state propagation	D	_	_	_	filter rate
Total orbiter acceleration	TOT_ACC	state propagation	V	DP	_	ft/sec^2	filter rate
The filter estimated sensor bias	SENSOR_BIAS	state propagation	V	DD	_	vary	filter rate
Gravitational constant of the earth	EARTH_MU	premission load	F	DP	_	ft^3/sec	filter rate
Square root of EARTH_MU	SQR_EMU	premission load	F	DP	_	ft^3/sec	filter rate

TABLE 4.3.2.7.7-1 - (Continued) COAS HORIZONTAL ANGLE MEASUREMENT INPUT PARAMETERS

DESCRIPTION	SYMBOL	INPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	SAMPLE RATE
Tolerance for successive iterations in the solution of Kepler's equation	EPS_KEP	premission load	F	DP	_	rad	filter rate
Maximum time skew between the measurement time and the time of the nav cycle before the state is interpolated to the measurement time	EPS_TIME	premission load	F	DP	_	sec	filter rate
Flag indicating processable data from the COAS sensor	COAS_DATA_GOOD	external sensor data snap	D	_	ON/OFF	_	filter rate
Variance of the COAS horizontal measurement	VAR_COAS_HORIZ	premission load	F	DD	_	rad^2	filter rate
Time tag for the COAS measurements	T_COAS	external data snap	F	DP	_	sec	filter rate
The COAS horizontal measurement	Q_COAS_HORIZ	external data snap	F	DP	_	rad	filter rate
M50 to body transformation matrix at the time the COAS data was snapped	M_M50_TO_BODY_COAS	external data snap	M	DP	_	_	filter rate

ORIGINAL PAGE IS OF POOR QUALITY

TABLE 4.3.2.7.7-1 (continued) COAS HORIZONTAL ANGLE MEASUREMENT INPUT PARAMETERS

DESCRIPTION	SYMBOL	INPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	SAMPLE RATE
Body to COAS transformation matrix	M_BODY_TO_COAS	premission load	M	DP	_	_	filter rate
Index indicating which COAS is being used	N_COAS_IN_USE	external data snap	D	DP	_	_	filter rate
Acceleration constants		*					

* Given in I-load requirements, section 4.8

TABLE 4.3.2.7.7-1 - COAS HORIZONTAL ANGLE MEASUREMENT OUTPUT PARAMETERS

DESCRIPTION	SYMBOL	OUTPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	COMPUTATION RATE
The navigation filter measurement residual	DELQ	Measurement Incorporation	F	DP	_	ft	filter rate
The measurement partials	B	Measurement Incorporation	V	DP	_	vary	filter rate
The general filter gain variance for the sensors	VAR	Measurement	F	DP	_	vary	filter rate

4.3.2.7.8 COAS vertical angle. The COAS vertical angle measurement subfunction computes an estimated vertical COAS angle, the angle measurement residual, and the vertical angle partial vector, and selects the proper variance to model the uncorrelated instrument error.

A. Detailed Requirements. A description of the symbols used in the following equations may be found in tables 4.3.2.7.8-1 and 4.3.2.7.8-2. This subfunction is exercised only when COAS data are selected and are valid.

First, the orbiter and target are interpolated to the time of the measurement and the orbiter and target transition matrices are calculated as described in section 4.3.2.7.1 where

$$DELTAT\_GO = T\_CURRENT\_FILT - T\_COAS$$

The partials are computed by the angle measurement partials subfunction as described in section 4.2.6. The parameters in that common subfunction must be given the following values prior to execution:

$$M\_M50\_TO\_SENSOR = M\_BODY\_TO\_COAS_{N\_COAS\_IN\_USE}$$

$$M\_M50\_TO\_BODY\_COAS$$

$$\underline{I\_N} = M\_M50\_TO\_SENSOR_{2,1\ to\ 3}$$

Calculation of the partial vector is completed by setting the appropriate value in the bias slot of that vector.

$$B_{16} = 1.0$$

The residual is calculated as follows:

$$\underline{U\_M} = M\_M50\_TO\_SENSOR\ \ UNIT(\underline{R\_RHO})$$

$$VERT = ARCTAN(U\_M/U\_M_3) + BIAS\_SENSOR_1$$

DELQ = Q_COAS_VERT-VERT

where R_RHO is defined by the partial calculation.

Finally the appropriate variance for the COAS vertical angle is assigned.

VAR = VAR_COAS_VERT

B. Interface Requirements. The input and output variables for the COAS vertical angle subfunction are given in tables 4.3.2.7.8-1 and 4.3.2.7.8-2.

C. Processing Requirements. This subfunction shall be performed after the state and covariance propagation, at the basic filter rate. This subfunction is performed as long as COAS measurements are being processed.

D. Constraints. None.

E. Supplementary Information. A suggested implementation of this subfunction is shown in flowcharts NAV_RENDEZVOUS, ANGLE_NAV, REND_NAV_INTERP, ONORBIT_SV_INTERP and MEAN_CONIC_PARTIAL_TRANSITION_MATRIX_6X6 in APPENDIX B.

TABLE 4.3.2.7.8-1 - COAS VERTICAL ANGLE MEASUREMENT INPUT PARAMETER

DESCRIPTION	SYMBOL	INPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	SAMPLE RATE
Filter current shuttle position vector in M50 coordinates	R_FILT	state propagation	V	DP	_	ft	filter rate
Filter current shuttle velocity vector in M50 coordinates	V_FILT	state propagation	V	DP	_	ft/sec	filter rate
Time tag for latest navigation cycle	T_CURRENT_FILT	state propagation	V	DP	_	sec	filter rate
Difference between accumulated sensed IMU readings on present cycle and previous cycle	DV_FILT	state propagation	V	DP	_	ft/sec	filter rate
The time interval of the last state and covariance propagation	DT_FILT	state propagation	F	DP	_	sec	filter rate
Position vector of the shuttle at the end of the last filter cycle	R_LAST	state propagation	V	DP	_	ft	filter rate

TABLE 4.3.2.7.8 -1 - (Continued) COAS VERTICAL ANGLE MEASUREMENT INPUT PARAMETERS

DESCRIPTION	SYMBOL	INPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	SAMPLE RATE
Velocity vector of the shuttle at the end of the last filter cycle	V_LAST	state propagation	V	DP	—	ft/sec	filter rate
Filter estimated target position at the end of the last filter cycle	R_TV_LAST	state propagation	V	DP	—	ft	filter rate
Filter estimated target position vector at the end of the last filter cycle	V_TV_LAST	state propagation	V	DP	—	ft/sec	filter rate
Current target position vector in M50 coordinates	R_TV	state propagation	V	DP	—	ft	filter rate
Current target velocity vector in M50 coordinates	V_TV	state propagation	V	DP	—	ft/sec	filter rate
Target's gravity vector at the end of the last integration interval	G_TV	state propagation	V	DP	—	ft/sec^2	filter rate
A discrete indicating the degree of the acceleration model used.	IGD	state propagation	D	—	—	—	filter rate

TABLE 4.3.2.7.8-1 - (Continued) COAS VERTICAL ANGLE MEASUREMENT INPUT PARAMETERS

DESCRIPTION	SYMBOL	INPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	SAMPLE RATE
A discrete indicating the order of the acceleration model to be used.	IGO	state propagation	D	_	_	_	filter rate
A flag indicating whether drag is to be modeled in the acceleration calculation.	IDM	state propagation	D	_	0-1	_	filter rate
A flag indicating whether venting is to be modeled in the acceleration equation	IVM	state propagation	D	_	0-1	_	filter rate
A discrete indicating the the type of atmosphere modeling to be used in the acceleration calculations	IATM	state propagation	D	_	_	_	filter rate
Total orbiter acceleration	TOT_ACC	state propagation	V	DD	_	ft/sec^2	filter rate
The filter estimated sensor bias	SENSOR_BIAS	state propagation	V	DP	_	vary	filter rate
Gravitational constant of the earth	EARTH_MU	premission load	F	DD	_	ft^3/sec	filter rate

TABLE 4.3.2.7.8-1 - (Continued) COAS VERTICAL ANGLE MEASUREMENT INPUT PARAMETERS

DESCRIPTION	SYMBOL	INPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	SAMPLE RATE
Square root of EARTH_MU	SQR_EMU	premission load	F	DP	_	ft^3/sec	filter rate
Tolerance for successive iterations in the solution of Kepler's equation	EPS_KEP	premission load	F	DP	_	rad	filter rate
Maximum time skew between the measurement time and the time of the nav cycle before the state is interpolated to the measurement time.	EPS_TIME	premission load	V	DP	_	sec	filter rate
Flag indicating processable data from the COAS sensor	COAS_DATA_GOOD	external sensor data snap	D	_	ON/OFF	_	filter rate
Variance of the COAS vertical measurement	VAR_COAS_VERT	premission load	F	DP	_	rad^2	filter rate
Time tag for the COAS measurements	T_COAS	external data snap	F	DP	_	sec	filter rate
The COAS vertical measurement	Q_COAS_VERT	external data snap	F	DP	_	rad	filter rate

ORIGINAL PAGE IS OF POOR QUALITY

TABLE 4.3.2.7.8-1 - (Continued) COAS VERTICAL ANGLE MEASUREMENT INPUT PARAMETERS

DESCRIPTION	SYMBOL	INPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	SAMPLE RATE
M50 to body transformation matrix at the time the COAS data was snapped	M_M50_TO_BODY_COAS	external data snap	M	DP	_	_	filter rate
Body to COAS transformation matrix	M_BODY_TO_COAS	premission load	M	DP	_	_	filter rate
Index indicating which COAS is being used.	N_COAS_IN_USE	external data snap	D	DP	_	_	filter rate
Acceleration constants		*					

* Given in I-load requirements, section 4.8

TABLE 4.3.2.7.8-1 - COAS VERTICAL ANGLE MEASUREMENT OUTPUT PARAMETERS

DESCRIPTION	SYMBOL	OUTPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	COMPUTATION RATE
The navigation filter measurement residual	DELQ	Measurement Incorporation	F	DP	—	ft	filter rate
The measurement partials	<u>B</u>	Measurement Incorporation	V	DP	—	vary	filter rate
The general filter gain variance for the sensors	VAR	Measurement Incorporation	F	DP	—	vary	filter rate

4.3.2.8 Measurement Processing Statistics

During rendezvous navigation phases that utilize external measurements, the measurement processing statistics subfunction will compute for display certain parameters that are indicative of the condition of the navigation filter and the external sensor measurements that it utilizes. These display parameters serve as the basis for the crew decision as to how external measurement data is to be processed by the nav filter. Three mutually exclusive controls are available to the crew which allow them to select one of the following processing options:

(1) AUTO - the nav filter edit criterion will determine whether or not valid data are to be used to update the state vector and covariance matrix.

(2) INHIBIT - valid data are to be utilized for computing display parameters but are not to be utilized to update the state vector and covariance matrix.

(3) FORCE - the nav filter edit criterion is to be overridden and valid data are to be utilized to update the state vector and covariance matrix whether or not the edit criterion is met.

The INHIBIT option will initially be in effect.

The measurement processing statistics subfunction will be performed after the corresponding state and covariance measurement incorporation subfunction has been performed. Filter edit indicators, which will have been initialized to a default value during the corresponding sensor measurement selection subfunction, will be redefined during

the performance of the state and covariance measurement incorporation subfunction. This will indicate to the measurement processing statistics subfunction, for each measurement type being utilized, which of the following five cases has occurred:

(1) edit indicator = OFF - the filter was not configured for the measurement type, or the data were bad and the filter did not attempt to process data of that type,

(2) edit indicator = ON - the filter did attempt to process the measurement type but automatically edited the data,

(3) edit indicator = PROCESSED - the filter processed the measurement type as a result of the data satisfying the edit criterion,

(4) edit indicator = STAT - the filter was used solely for producing the residual and ratio parameters for display, or

(5) edit indicator = FORCED - the filter processed the data as a result of a crew edit override.

Moreover, the state and covariance measurement incorporation subfunction will provide the measurement processing statistics subfunction with the value of each measurement residual and the square of each residual edit criterion value. The data supplied to the measurement processing statistics subfunction are used to compute statistics for the sensor measurement type selected.

For each measurement type, the following parameters are to be computed for display to show how well the navigation filter is processing external measurements of that particular type:.

$DISP\_DELQ_I$ - the actual measurement residual computed by the nav filter for the I'th measurement type. If valid data were not presented to the nav filter, then $DISP\_DELQ_I$ shall be set to "BLANK" in accordance with display requirements.

$DISP\_SIG_I$ - the edit ratio for the I'th measurement type, which is the absolute magnitude of the actual measurement residual divided by the maximum magnitude that the residual may attain before automatic data editing by the filter occurs. As above, $DISP\_SIG_I$ shall be set to "BLANK" whenever valid data for this measurement type was not presented to the filter.

N_ACCEPT_I - the number of data marks for the I'th measurement type, which have been used to update the nav state vector.

N_REJECT_I - the number of data marks for the I'th measurement type which have been automatically rejected as a result of failing the nav filter edit criterion.

$DISP\_EDIT_I$ - the status indicator which shall be displayed as a "BLANK" unless the nav filter has edited a predetermined number of sequential data marks for the I'th type. In this case, the status indicator shall be displayed as the symbol, "↓". Once set, the down arrow symbol shall continue to be displayed until a predetermined number of sequential data marks have been automatically processed by the nav filter or until the crew exercises the edit override (FORCE).

The accept/reject counters are initialized to zero whenever the rendezvous navigation major mode is entered (MM211), whenever the

onorbit coast major mode is entered (MM201), whenever the sensor type is changed, or whenever a ground state update occurs.

Sensor data will consist of two types - angular data and range data. The angular data will consist of a pair of angles from one of three mutually exclusive sources; COAS, star tracker (ST) or rendezvous radar (RR). The range data will consist of range and range rate from the rendezvous radar. Angular data, from whichever source has been chosen, can be utilized in conjunction with range data.

A. Detailed Requirements. - The correspondence between the measurement type and the subscript, I, shall be as follows:

I = 1 - COAS horizontal angle, ST horizontal angle or RR shaft angle

I = 2 - COAS vertical angle, ST vertical angle or RR trunnion angle

I = 3 - RR range

I = 4 - RR range rate

For each value of the integer I in the interval (1, 4), the following procedure will be performed.

The indicator $SENSOR\_EDIT_I$ shall be tested; and if found to have the value "OFF", both $DISP\_DELQ_I$ and $DISP\_SIG_I$ shall be given the value "BLANK" and the calculations shall cease at this point. If the value tested is not "OFF", then $DISP\_DELQ_I$ shall be given the value $SENSOR\_DELQ_I$ and $DISP\_SIG_I$ shall be calculated according to

$$DISP\_SIG_I = \frac{ABS(SENSOR\_DELQ_I)}{(SENSOR\_RESID\_TEST_I)^{1/2}}$$

provided that $SENSOR\_RESID\_TEST_I$ is positive.

The $SENSOR\_EDIT_I$ indicator shall again be tested; and if found to have the value "STAT", $DISP\_EDIT_I$ shall be given the value "BLANK" and the calculations shall cease at this point.

If the value is not "STAT", the $SENSOR\_EDIT_I$ indicator shall be tested again, and if found to have the value "ON", the sequential accept counter shall be set to zero ($SEQ\_ACCEPT_I = 0$), the sequential reject counter shall be incremented by one ($SEQ\_REJECT_I = SEQ\_REJECT_I + 1$), and the counter for the number of marks rejected by the nav filter shall be incremented by one ($N\_REJECT_I = N\_REJECT_I + 1$). Then SEQ_REJECT_I is to be tested and, if found to exceed a predetermined number (REJ_MAX), $DISP\_EDIT_I$ shall be set to "↓".

If the value for $SENSOR\_EDIT_I$ was not "ON", the sequential reject counter shall be set to zero ($SEQ\_REJECT_I = 0$), the sequential accept counter shall be incremented by one ($SEQ\_ACCEPT_I = SEQ\_ACCEPT_I + 1$), and the counter for the number of marks processed by the nav filter shall be incremented by one ($N\_ACCEPT_I = N\_ACCEPT_I + 1$). Finally $DISP\_EDIT_I$ is to be given the value "BLANK" whenever $SENSOR\_EDIT_I$ has a value of "FORCED" or whenever SEQ_ACCEPT_I exceeds a predetermined number (ACC_MIN).

B. Interface Requirements. Input and output parameters are listed in tables 4.3.2.8-1 and 4.3.2.8-2.

C. Processing Requirements. None

D. Constraints. None

E. Supplementary Information. A suggested implementation for this subfunction may be found in the detailed flow chart of Appendix B entitled: MEAS_PROCESSING_STATISTICS_REND.

TABLE 4.3.2.8-1: MEASUREMENT PROCESSING STATISTICS INPUT PARAMETERS

DESCRIPTION	SYMBOL	INPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	SAMPLE RATE
Measurement residual for the I'th measurement type, I=1,4	SENSOR_DELQ(I)	Rend. navigation state and covariance measurement incorporation	F	S			
Value of criterion used in nav filter for residual edit test for I'th measurement type, I=1,4	SENSOR_RESID_TEST(I)	Rend. navigation state and covariance measurement incorporation	F	S			
Five valued flag defining use of I'th measurement data by the nav filter, I=1,4. OFF - no processing attempted. ON - rejected by residual edit test. PROCESSED - accepted by residual edit test and used to update state vector. STAT - used to generate display parameters. FORCED - used to update state vector as a result of manual edit override.	SENSOR_EDIT(I)	Rend. navigation state and covariance measurement incorporation	CHAR	S			

TABLE 4.3.2.8-1: MEASUREMENT PROCESSING STATISTICS INPUT PARAMETERS (CONTINUED)

DESCRIPTION	SYMBOL	INPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	SAMPLE RATE
Counter for the number of data marks, for the I'th measurement type, which have been utilized to update the nav state vector, I = 1,4.	N_ACCEPT_I	State and covariance setup,*	F	S			
Counter for the number of data marks, for the I'th measurement type, which have been edited by the nav filter.	N_REJECT_I	State and covariance setup,*	F	S			

*Rendezvous navigation principal function input list.

TABLE 4.3.2.8-2: MEASUREMENT PROCESSING STATISTICS OUTPUT PARAMETERS

DESCRIPTION	SYMBOL	OUTPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	COMPUTATION RATE
Display measurement residual for I'th measurement type, I=1,4	DISP_DELQ$_I$	*	F	DP		VAR.	
Display residual edit ratio for I'th measurement type, I=1,4	DISP_SIG$_I$	*	F	DP			
Display edit status indicator for I'th measurement type, I=1,4	DISP_EDIT$_I$	*	CHAR	S			
Counter for the number of data marks, for the I'th measurement type, which have been utilized to update the nav state vector, I=1,4	N_ACCEPT$_I$	*	F	S			
Counter for the number of data marks, for the I'th measurement type, that have been edited by the nav filter, I=1,4	N_REJECT$_I$	*	F	S			

*Rendezvous navigation principal function output list.

4.5 General Requirement Principal Functions

This section delineates software requirements in the category of service, single use or multiple use, that are not specifically function related. The general requirement principal functions include, but are not limited to, the following:

1. Site lookup principal function (Section 4.5.1).
2. Onorbit precision state prediction principal function (Section 4.5.2).
3. Star Tracker SOP Ephemerides (Seciton 4.5.3).

4.5.2 Onorbit Precision State Prediction

A capability shall be provided for predicting the position and velocity of the orbiter or target at some final time in the future or past, when an initial state and time are given.

The onorbit precision state prediction principal function shall make no use of the IMU accumulated sensed velocities and therefore is a free-flight prediction process even though it may be performed during periods of flight in which navigation is using accumulated sensed velocities.

Since this principal function shall be used for different purposes having different environmental requirements in various navigation phases, the user shall, by setting the control flags to the appropriate values and by choosing the prediction method or integration step size, have the option to trade off the accuracy of the integration and the fidelity of the mathematical models in favor of the shorter execution time. This is accomplished with parameters specified in the input argument list.

Tables 4.5.2-1 and 4.5.2-2 are principal function input and output lists which show data flow between the onorbit precision state prediction principal function and other principal functions.

A. Detailed requirements. This principal function, which provides for onorbit precision state prediction of the orbiter or target position/velocity states, shall use either a fourth-order Runge-Kutta numerical integration technique, modified with Gill's coefficients, together with an Adams-Moulton predictor-corrector integrator or a single-step two-body method. The S. Pines formulation of the equations of motion shall be used with each technique. Detailed requirements for the Runge-Kutta-Gill integration technique and the Pines formulation are provided in the precision integration subfunction (sec. 4.2.1.3.2). The Runge-Kutta-Gill integrator is used as the starter (Adams-Moulton integration is not self-starting) for the Adams-Moulton technique and shall be shared with the precision integration subfunction, together with the Pines formulation of the equations of motion. Noncentral body accelerations shall be generated by the user-selected acceleration models (sec. 4.2.1.2) to account for perturbations due to drag, venting and uncoupled thrusting, and variations in the Earth's gravitational potential. The onorbit precision state prediction principal function computational scheme shall be performed as follows:

1. The desired gravity (GMD and GMO), drag (DM), venting and uncoupled thrusting (VM), and vehicle-attitude (ATM) mode flags shall be obtained from the user, together with the prediction integration step size (DELTA_T), initial state and time (R _IN, V _IN, and T_IN), and final time at the end of the prediction interval (T_FIN).

2. The initial state vector shall then be renamed for use in the Pines equations-of-motion formulation and the seventh variable of integration (XN_7) initialized to zero:

$$XN_{1 \text{ to } 3} = \underline{R}\_IN$$

$$XN_{4 \text{ to } 6} = \underline{V}\_IN$$

$$XN_7 = 0.$$

In the above equations, the seventh variable of integration (XN_7 , required by the Pines technique), is the integrated initial time T_IN.

3. A check shall now be made on the gravity mode flag (GMD) to determine if prediction is to be accomplished through the use of a simple two-body solution or a more precise integration technique. If a two-body solution is required, (i.e., GMD = 0) the prediction interval is computed,

T_CUR = T_FIN - T_IN

and the Pines equations-of-motion formulation is called to propagate the initial state ($\underline{R}$_IN, $\underline{V}$_IN) from the initial time (T_IN) to the final time (T_FIN) in a single step using the two-body solution portion of the Pines equations-of-motion formulation.

4. Otherwise, (GMD≠0), the Adams-Moulton flag is set to OFF, the current integrator time (T_CUR) is set to zero, and the step size is set as input:

AM = OFF

T_CUR = 0.

DT_STEP = DELTA_T

Additionally, the input integration step size is checked to determine if it is greater than a pre-stored maximum (DT_MAX). If the input step size is greater than the pre-stored maximum (i.e., DT_STEP DT_MAX), the step size used will be set at the maximum.

$$\text{DT\_STEP} = \text{DT\_MAX}$$

5. Next, the number of integration steps (N_STEPS) required for the input integration interval shall be calculated:

$$\text{N\_STEPS} = \text{CEILING}\left(\frac{|\text{T\_FIN} - \text{T\_IN}|}{\text{DT\_STEP}}\right)$$

$$\text{DT\_STEP} = \frac{\text{T\_FIN} - \text{T\_IN}}{\text{N\_STEPS}}$$

6. A check shall now be made to determine if the number of steps is sufficient to require the use of the Adams-Moulton predictor-corrector. If the number of steps required for the integration interval is greater than or equal to the order of the Adams-Moulton integrator (i.e., N_STEPS $\geq$ MORDER), then the Adams-Moulton flag, AM, shall be set to ON - a setting indicating the use of the Adams-Moulton technique. This setting shall cause the Runge-Kutta-Gill starter to store the derivatives of the integrated initial conditions (DERIV) in a table (AM_TABLE) on the first Runge-Kutta evaluation for each integration step:

$$\text{AM\_TABLE}_{I,L} = \text{DERIV}_{L}$$

where

$$I = 1 \text{ to MORDER} - 1$$

L = 1 to 7

The last (MORDER) derivative shall be stored following the call to the Pines formulation after the last Runge-Kutta-Gill step. Should there not be enough integration steps to require use of the Adams-Moulton integrator, this principal function shall provide for precision state prediction with use of only the Runge-Kutta-Gill technique (i.e., AM = OFF). Storage of the above derivatives shall then be by-passed.

7. The actual integration of the orbiter or target state equations (formulated according to the Pines technique) shall now be performed by proceeding as follows for each step in the integration interval. Note that, in the Pines equations-of-motion formulation, it is the initial conditions ($\underline{R}$ _IN , $\underline{V}$ _IN, and T_IN) that are integrated and then used in the closed-form solution of a two-body, unperturbed orbital problem using an F- and G-series type of expression.

The fourth-order Runge-Kutta-Gill integration technique shall be invoked in conjunction with the Pines equation-of-motion formulation. When the Adams-Moulton technique is also required, the Runge-Kutta-Gill integrator shall construct the table of derivatives (AM_TABLE) as described previously.

During onorbit precision state prediction requiring only Runge-Kutta-Gill, integration shall continue until the number of steps in the integration interval have been completed. When both integration techniques are required (Runge-Kutta-Gill and Adams-Moulton), the Runge-Kutta-Gill technique

shall be invoked until N_STEPS = MORDER - 1; then, the Adams-Moulton technique shall be employed for the remaining steps. The Pines equations-of-motion formulation shall be invoked after the final call to the Runge-Kutta-Gill integrator (I = MORDER - 1), and the integrated initial condition derivatives shall be stored:

$$\text{AM\_TABLE}_{I+1,M} = \text{DERIV}_{M}$$

where

$$I = \text{MORDER} - 1$$

$$M = 1 \text{ to } 7$$

When the number of integration steps required exceeds MORDER - 1 and the table of derivatives has been constructed with the aid of the Runge-Kutta-Gill starter, the Adams-Moulton integration technique shall proceed as follows for each integration step:

a. First, the predictor calculations are performed for each variable of integration (J = 1,7):

$$XP_{J} = XN_{J}$$

$$\text{SUM} = 0.0$$

$$\text{SUM} = \text{SUM} + \text{AM\_TABLE}_{1 \text{ to MORDER},J} \; \text{PRED\_COEF}_{1 \text{ to MORDER}}$$

$$XN_{J} = XN_{J} + \text{DT\_STEP SUM}$$

where

XP = value of the integrated initial conditions before prediction

XN = integrated initial conditions

AM_TABLE = a table of MORDER derivatives of the integrated initial conditions

PRED_COEF = a table of premission-selected coefficients

DT_STEP = integration step size

b. The current time within the integrator is incremented:

$$T\_CUR = T\_CUR + DT\_STEP$$

c. The Pines equations-of-motion formulation is exercised to calculate the derivatives of the predicted integrated initial conditions.

d. Next, the corrector calculations are performed in a manner similar to the predictor equations (i.e., J = 1, 7):

$$SUM = 0.0$$

$$SUM = SUM + AM\_TABLE_{2\ to\ MORDER,J}\ CORR\_COEF_{1\ to\ MORDER-1}$$

$$XN_J = XP_J + DT\_STEP\ (DERIV_J\ CORR\_COEF_{MORDER} + SUM)$$

e. Another call shall now be made to exercise the Pines formulation to calculate the derivates of the integrated initial conditions (position, velocity and initial time) and, on the final integration step, compute the position and velocity vectors ($X_{1\ to\ 3}$ and $X_{4\ to\ 6}$) by applying the integrated initial conditions to the Pines equations defining the closed-form two-body solution.

f. If additional integration steps are required, the Adams-Moulton table of derivatives (AM_TABLE) shall be updated as follows for each variable of integration (J = 1 , 7):

$$AM\_TABLE_{1\ to\ MORDER-1,J} = AM\_TABLE_{2\ to\ MORDER,\ J}$$

ORIGINAL PAGE IS
OF POOR QUALITY

$$\underline{AM\_TABLE}_{MORDER,J} = DERIV_J$$

After the computed number of integration steps have been completed (whether with Runge-Kutta-Gill alone or in conjunction with the Adams-Moulton or a single step two-body solution), the position and velocity are renamed for output:

$$\underline{R}\_FIN = X_{1 \text{ to } 3}$$

$$\underline{V}\_FIN = X_{4 \text{ to } 6}$$

B. Interface requirements. Input and output requirements are contained in tables 4.5.2-3 and 4.5.2-4.

C. Processing requirements. This principal function requires user-supplied values of gravity (GMO and GMD), drag (DM), venting and uncoupled thrusting (VM), and vehicle-attitude (ATM) mode flags, in conjunction with the initial state and time (R_IN, V_IN, T_IN) and the final time (T_FIN). Appropriate acceleration models may be found in section 4.2.1.2 . When using this function for target vehicle state prediction the venting and uncoupled thrusting flag (VM) shall be set to zero. Additionally, if drag modeling is desired, the drag mode flag (DM) should be set to one and the attitude mode flag (ATM) set greater than or equal to three as appropriate for the specific target.

D. Constraints. This module may only be invoked during onorbit or rendezvous coasting flight. The minimum step size (DELTA_T) and maximum prediction interval (T_FIN - T_IN)

is restricted by the maximum number of integer steps which can be stored into the orbiter's onboard computer in single precision (i.e. 32767 steps). The user shall supply the appropriate step size and prediction interval such that the maximum number of steps never exceeds 32767 (AP-101 maximum standard single precision integer).

E. Supplementary information. The onorbit precision state prediction principal function shall be used for both precision and rapid state prediction. When a rapid state prediction is desired, two options are available. The first uses a sophisticated integration technique and equations of motion formulation, while the second method performs the rapid prediction with a less accurate, single-step two-body F and G series solution involving no numerical integration. A suggested implementation of this principal function may be found in appendix B. The following table lists several examples of input variable list combinations for the various types of prediction performed:

VEHICLE	PREDICTION TYPE	GMD*	GMO*	DM	VM	ATM	STEP-SIZE	COMMENTS
Orbiter	Precision	8	8	1	1	1	user selects	Full 8th degree potential model, Drag and venting with predicted attitude & venting timeline
Orbiter	Rapid precison	2	0	1	0	2	user selects	J_2 only potential model with constant drag coeffieient, area
Orbiter	Rapid 2-body	0	0	0	0	0	0	Single-step two-body F and G series solution
Target	Precison	8	8	1	0	≥ 3	user selects	Full 8th degree potential model drag with constant area, drag coefficient
Target	Rapid precision	2	0	1	0	≥ 3	user selects	J_2 only potential model with constant drag coefficient, area
Target	Rapid 2-body	0	0	0	0	0	0	Single-step two-body F and G series solution

* When prediction is being performed for both vehicles (orbiter and target) over a similar trajectory, the same degree and order potential model should be used for each prediction so that potential model errors will be avoided.

TABLE 4.5.2-2: ONORBIT PRECISION STATE PREDICTION PRINCIPAL FUNCTION INPUT

LEVEL B MNEMON	LEVEL C FSSR VARIABLE NAME	EXTERNAL PRINCIPAL FUNCTION SOURCE	INTERNAL SUBFUNCTION DESTINATION (SUBFUNCTIONS WITHIN THIS PRINCIPAL FUNCTION WHICH UTILIZE THE VARIABLE)	
			SUBFUNCTION NAME	SUBFUNCTION INPUT TABLE
TBD	GMD	Onorbit NAV, REND NAV, ONORBIT GUIDANCE	N/A	N/A
	GMO			
	DM			
	VM			
	ATM			
	DELTA_T			
	R_IN			
	V_IN			
	T_IN			
	T_FIN			
	SQR_EMU	ONORBIT/REND NAV SEQUENCER	N/A	N/A

TABLE 4.5.2-2: ONORBIT PRECISION STATE PREDICTION OUTPUT LIST

LEVEL B MNEMON	LEVEL C FSSR VARIABLE NAME	EXTERNAL PRINCIPAL FUNCTION SOURCE	INTERNAL SUBFUNCTION DESTINATION (SUBFUNCTIONS WITHIN THIS PRINCIPAL FUNCTION WHICH UTILIZE THE VARIABLE)	
			SUBFUNCTION NAME	SUBFUNCTION INPUT TABLE
	R_FIN V_FIN	ONORBIT NAV, REND NAV, ONORBIT GUI-DANCE	N/A	N/A
TBD				

TABLE 4.5.2-3 ONORBIT PRECISION STATE PREDICTION INPUT PARAMETERS

DESCRIPTION	SYMBOL	INPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	SAMPLE RATE
FLAG INDICATING THE DEGREE OF THE GRAV POTENTIAL MODEL	GMD	*	I	S	0-8		AS NEEDED
FLAG INDICATING THE ORDER OF THE GRAV POTENTIAL MODEL	GMO	*	I	S	0-8		AS NEEDED
FLAG INDICATING CHOICE OF MODELS FOR ACCELERATION DUE TO DRAG	DM	*	I	S	0,1		AS NEEDED

* Refer to onorbit precision state prediction principal function input list

TABLE 4.5.2-3 ONORBIT PRECISION STATE PREDICTION INPUT PARAMETERS - Continued

DESCRIPTION	SYMBOL	INPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	SAMPLE RATE
INTEGRATION STEP SIZE FOR PREDICTION OR PROPAGATION	DELTA_T	*	F	DP		SEC	AS NEEDED
SHUTTLE POSITION VECTOR AT T_IN	R_IN	*	V(3)	DP		FT	AS NEEDED
SHUTTLE VELOCITY VECTOR AT T_IN	V_IN	*	V(3)	DP		FT/SEC	AS NEEDED

* Refer to onorbit precision state prediction principal function input list

TABLE 4.5.2-3 ONORBIT PRECISION STATE PREDICTION INPUT PARAMETERS - Continued

DESCRIPTION	SYMBOL	INPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	SAMPLE RATE
INITIAL TIME INPUT FOR ONORBIT PREDICTION OR PROPAGATION	T_IN	*	F	DP		SEC	AS NEEDED
FINAL TIME AT END OF PREDICTION OR PROPAGATION	T_FIN	*	F	DP		SEC	AS NEEDED
THE ORDER OF THE ADAMS-MOULTON INTEGRATOR	MORDER	PREMISSION LOAD	I	S			AS NEEDED
ARRAY OF COEFFICIENTS REQUIRED BY THE RK-GILL INTEGRATOR	A	CONSTANTS	F	DP			AS NEEDED
ARRAY OF COEFFICIENTS REQUIRED BY THE RK-GILL INTEGRATOR	B	CONSTANTS	F	DP			AS NEEDED
ARRAY OF COEFFICIENTS REQUIRED BY THE RK-GILL INTEGRATOR	C	CONSTANTS	F	DP			AS NEEDED

* Refer to onorbit precision state prediction principal function input list

TABLE 4.5.2-3 ONORBIT PRECISION STATE PREDICTION INPUT PARAMETERS - Concluded

DESCRIPTION	SYMBOL	INPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	SAMPLE RATE
ARRAY OF COEFFICIENTS REQUIRED BY THE RK-GILL INTEGRATOR	D	CONSTANTS	F	DP			AS NEEDED
ARRAY OF MORDER COEFFICIENTS USED IN THE ADAMS-MOULTON CORRECTOR	PRED_COEF	CONSTANTS	F	DP			AS NEEDED
GRAVITATIONAL CONSTANT OF EARTH	EARTH_MU	CONSTANTS	F	DP		FT**3/SEC**2	AS NEEDED
SQUARE-ROOT OF EARTH_MU, USED IN ONORBIT PRED/PRLP INTEGRATION (PINES) METHOD	SQR_EMU	*	F	DP		$(FT**3/SEC**2)^{\frac{1}{2}}$	AS NEEDED
FLAG INDICATING WHICH VENTING MODEL IS TO BE USED BY PRECISION STATE PREDICTOR	VM	*	I	S	0,1		AS NEEDED
ATTITUDE MODE FLAG	ATM	*	I	S	0,1,2 (Orbiter) ≥ 3 (target)		AS NEEDED
MAXIMUM INTEGRATION STEP SIZE USED FOR PRECISION PREDICTION	DT_MAX	PREMISSION LOAD	F	DP		SEC	AS NEEDED

* Refer to onorbit precision state prediction principal function input list

TABLE 4.5.2-4-ONORBIT PRECISION STATE PREDICTION OUTPUT PARAMETERS

DESCRIPTION	SYMBOL	OUTPUT DESTINATION	TYPE	PRECISION	RANGE	UNITS	COMPUTATION RATE
SHUTTLE POSITION VECTOR AT T_FIN	R_FIN	*	V(3)	DP		FT	AS NEEDED
SHUTTLE VELOCITY VECTOR AT T_FIN	V_FIN	*	V(3)	DP		FT/SEC	AS NEEDED

* Refer to onorbit precision state prediction principal function output list

4.6 User Parameter Processing Principal Function (Onorbit)

This principal function shall serve as the interface between navigation and users of navigation-related data during the onorbit operational sequence. This function shall maintain the vehicle state within the user parameter state propagation subfunction and shall:

a) provide this state to users who require vehicle state parameters in mean-of-fifty (M50) coordinates; and

b) provide the software to transform this state for users who require nav state-related parameters.

Interface parameters between this principal function and other GN&C principal functions are presented in tables 4.6-1 and 4.6-2.

TABLE 4.6-1: ONORBIT USER PARAMETER PROCESSING PRINCIPAL FUNCTION INPUT LIST

LEVEL B MNEMON	LEVEL C FSSR VARIABLE NAME	EXTERNAL PRINCIPAL FUNCTION SOURCE	INTERNAL SUBFUNCTION DESTINATION (SUBFUNCTIONS WITHIN THIS PRINCIPAL FUNCTION WHICH UTILIZE THE VARIABLE)	
			SUBFUNCTION NAME	SUBFUNCTION INPUT TABLE
G14702 - G14704	V_IMU_CURRENT	IMU_RM	USER_PARAM_PROPAGATOR	4.6.1-1
G14705	T_IMU	"	"	"
G28201- G28203	R_RESET	ORB NAV RENDZ NAV ORB/RND NAV SEQ	"	"
G28204- G28206	V_RESET	RENDZ NAV ORB NAV ORB/RND NAV SEQ	"	"
G29701	T_RESET	RENDZ NAV ORB NAV ORB/RND NAV SEQ	"	"
G28210 - G28212	V_IMU_RESET	RENDZ NAV ORB NAV ORB/RND NAV SEQ	"	"
G46500	USE_IMU_DATA	RENDZ NAV ORB NAV	"	"
G25515	FILT_UPDATE	REND NAV ORB NAV ORB/RND NAV SEQ	"	"

ORIGINAL PAGE IS
OF POOR QUALITY

TABLE 4.6-1: ONORBIT USER PARAMETER PROCESSING PRINCIPAL FUNCTION INPUT LIST (con't.)

LEVEL B MNEMON	LEVEL C FSSR VARIABLE NAME	EXTERNAL PRINCIPAL FUNCTION SOURCE	INTERNAL SUBFUNCTION DESTINATION (SUBFUNCTIONS WITHIN THIS PRINCIPAL FUNCTION WHICH UTILIZE THE VARIABLE)	
			SUBFUNCTION NAME	SUBFUNCTION INPUT TABLE
TBD	COMP_MODE	NAV MONITOR DIP	NAV_MONITOR_COMPS	4.6.2-1
"	DO_PREDICT	"	"	"
"	T_PREDICT	"	"	"
"	R_COMP	ONORBIT PREDICT	"	"
"	V_COMP	"	"	"
"	REND_NAV_FLAG	ORB/RND NAV SEQ	USER_PARAM_PROPAGATOR	4.6.1-1
"	R_TV_RESET	RENDZ NAV ORB/RND NAV SEQ	"	"
"	V_TV_RESET	RENDZ NAV ORB/RND NAV SEQ	"	"

TABLE 4.6.2: ONORBIT USER PARAMETER PROCESSING PRINCIPAL FUNCTION OUTPUT LIST

LEVEL B MNEMON	LEVEL C FSSR VARIABLE NAME	EXTERNAL PRINCIPAL FUNCTION SOURCE	INTERNAL SUBFUNCTION DESTINATION (SUBFUNCTIONS WITHIN THIS PRINCIPAL FUNCTION WHICH UTILIZE THE VARIABLE)	
			SUBFUNCTION NAME	SUBFUNCTION INPUT TABLE
G02701- G02703	R_AVGG	ON-ORB GUID ATT PROC ORBIT MNVR DIP GN&C/SM-PL IF	USER_PARAM_PROPAGATOR	4.6.1-2
G02704- G02706	V_AVGG	ON-ORB GUID ATT PROC ORBIT MNVR DIP GN&C/SM-PL IF	"	"

TABLE 4.6-2: ONORBIT USER PARAMETER PROCESSING PRINCIPAL FUNCTION OUTPUT LIST (con't.)

LEVEL B MNEMON	LEVEL C FSSR VARIABLE NAME	EXTERNAL PRINCIPAL FUNCTION SOURCE	INTERNAL SUBFUNCTION DESTINATION (SUBFUNCTIONS WITHIN THIS PRINCIPAL FUNCTION WHICH UTILIZE THE VARIABLE)	
			SUBFUNCTION NAME	SUBFUNCTION INPUT TABLE
G02707	T_STATE	ON-ORB GUID ORBIT MNVR DIP GN&C/SM-PL IF	USER PARAM PROPAGATOR	4.6.1-2
G02712- G02714	V_IMU_OLD	ON-ORB GUID	"	"
TBD	LATITUDE	NAV MONITOR DIP	NAV_MONITOR_COMPS	4.6.2-2
"	LONGITUDE	"	"	"
"	ALTITUDE	"	"	"
"	ASC_NODE	"	"	"
G02701- G02703	R_AVGG	ONORBIT PREDICT	"	"
G02704- G02706	V_AVGG	"	"	"
G02707	T_STATE	"	"	"
TBD	T_PREDICT	"	"	"
"	DT_PREDICT	"	"	"

4.6.1 User Parameter State Propagation

Whereas the on-orbit and rendezvous navigation state propagation subfunctions advance the navigation state vector at relatively large intervals, at the end of which external measurement data processed by the filter are incorporated when appropriate, users such as guidance and displays require a knowledge of the state vector at shorter intervals.

The on-orbit and rendezvous user parameter state propagation subfunction will satisfy the requirements of such users by integrating the equations of motion within the intervals of the navigation propagation with use of a simplified computation of the gravitational acceleration in conjunction with a small step size.

In the case of the orbiter, if an indication exists that the acceleration derived from the IMU sensed velocities is above a certain threshold level, this acceleration is to be used in the integration process. The information about the acceleration level takes the form of a flag (USE_IMU_DATA) which is set to ON or OFF by the navigation state propagation. The integration is to be performed by an average-g process, using a modeled acceleration that contains only the central force term and the J_2 zonal harmonic of the Earth's gravitational force. If the USE_IMU_DATA flag is found to be set to ON, the sensed acceleration shall be used

in addition to the model acceleration. If the USE_IMU_DATA flag is found to be OFF, only the modeled acceleration is to be utilized in the integration.

In the rendezvous phases it is also necessary to propagate the target vehicle state. There being no IMU's in this vehicle, only the modeled acceleration is to be used in the integration.

This process will be restarted after each filter update with the filter states. The values of the filter updated position and velocity vectors, together with their time tag and the total accumulated IMU velocity, are stored (at each navigation cycle) in special locations for use by the user parameter state propagation subfunction. This prevents the errors resulting from use of a less accurate integrating scheme from becoming too large and, at the same time, provides a synchronization between the propagation tasks.

A. Detailed Requirements

A capability shall be provided for a fast computation of the position and velocity of the orbiter during all phases of OPS-2, and of the position and velocity of the target vehicle during all rendezvous phases. This computation shall provide the required state vectors in a M50 coordinate system by the integration of the equations of motion that include gravity accelerations and, for the orbiter, the IMU sensed velocities, if

they give a significant contribution.

In the case of the orbiter, the value of the state that is to be advanced(integrated forward in time) may be from one of two sources (the one used depends on the tested value of the flag (FILT_UPDATE), which indicates the availability of a filter updated state):

1. If an update from the filter is not available (condition OFF), the propagated state, saved from the previous cycle, is to be advanced. The value of the IMU-accumulated sensed velocity from the previous cycle is available for state advancement purposes.
2. If an update from the filter is available (condition ON), the navigation filter updated state, together with its time tag and associated IMU accumulated sensed velocity, is to replace the previous propagated state, time tag, and accumulated velocity. The filter updated values are $\underline{R}$_RESET, $\underline{V}$_RESET, T_RESET and $\underline{V}$_IMU_RESET; the vectors maintained by the user parameter state propagator are $\underline{R}$_AVGG and $\underline{V}$_AVGG. The time tag is T_STATE. Thus, if FILT_UPDATE = ON, the following will be done:

   $\underline{R}$_AVGG = $\underline{R}$_RESET

   $\underline{V}$_AVGG = $\underline{V}$_RESET

   $\underline{V}$_IMU_OLD = $\underline{V}$_IMU_RESET

   T_STATE = T_RESET

The computational sequence required is as follows:

1. Snap the IMU accumulated sensed velocity and time tag:

   SNAP(V_IMU_CURRENT, T_IMU)

2. Test the filter update flag (FILT_UPDATE) and take the appropriate aforementioned action.

3. Compute the interval over which advancement is required:

   DT_IMU = T_IMU - T_STATE

4. Test the USE_IMU_DATA flag. Then, if the value of the flag is found to be ON, set

$$\underline{\text{A}}\text{\_SENSED} = \frac{\underline{\text{V}}\text{\_IMU\_CURRENT} - \underline{\text{V}}\text{\_IMU\_OLD}}{\text{DT\_IMU}}$$

   If the value of the USE_IMU_DATA flag is OFF, set

   A_SENSED = 0.

5. The position and velocity vectors of the orbiter shall then be obtained by a call to the user state integrator

   CALL: AVERAGE_G_INTEGRATOR

   IN LIST: R_AVGG, V_AVGG, DT_IMU, A_SENSED, T_STATE, T_IMU

   OUT LIST: R_AVGG, V_AVGG

The calculations performed up to this point refer to the orbiter's state. Propagation of the target state is required only during the rendezvous phases. A flag (REND_NAV_FLAG), which has the value ON only during these phases, shall then be consulted by the user parameters state propagator.

6. Test the REND_NAV_FLAG. If it is found to be ON, test

the FILT_UPDATE flag to determine if a filter updated target state is available.

If FILT_UPDATE = ON, set

R_TARGET = R_TV_RESET

V_TARGET = V_TV_RESET

where R_TARGET and V_TARGET represent the position and velocity vectors of the target vehicle advanced by the user parameter state propagator, and R_TV_RESET and V_TV_RESET the target state vectors from the navigation filter.

7. Advance the target state by a call to the integrator. In this call, the vector that contains the sensed acceleration shall be set to zero.

   CALL: AVERAGE_G_INTEGRATOR

   IN LIST: R_TARGET, V_TARGET, DT_IMU, 0., 0., 0., T_STATE, T_IMU

   OUT LIST: R_TARGET, V_TARGET

After the state vector updates have been completed, the following steps are to be executed:

8. Save the time tag output for use in the next cycle:

   T_STATE = T_IMU

9. Save the latest IMU accumulated sensed velocity:

   V_IMU_OLD = V_IMU_CURRENT

10. Set the FILT_UPDATE flag to OFF.

This completes the sequence of calculations of a user parameter state propagation cycle.

The detailed integrator equations follow:

AVERAGE_G_INTEGRATOR

IN LIST: $\underline{\text{R}}\text{ AV}$, $\underline{\text{V}}\text{ AV}$, DTIME, $\underline{\text{AC}}$, T_STATE, T_IMU

OUT LIST: $\underline{\text{R}}\text{ AV}$, $\underline{\text{V}}\text{ AV}$

1. By means of a call to the acceleration function, find the gravitational acceleration up to degree 2 and order 0 for the input state vector and corresponding time tag;

$$\underline{\text{GR}} = \underline{\text{ACCEL\_PERT\_ONORBIT}}\ (2, 0, 0, 0, 0, \underline{\text{R}}\text{ AV}, \underline{\text{V}}\text{ AV}, \text{T\_STATE}) - \text{EARTH\_MU}\ \underline{\text{R}}\text{ AV}/|\underline{\text{R}}\text{ AV}|^3$$

2. advance the position vector by the average-g method:

$$\underline{\text{R}}\text{ AV} = \underline{\text{R}}\text{ AV} + \text{DTIME}\ [\underline{\text{V}}\text{ AV} + .5\ \text{DTIME}\ (\underline{\text{AC}} + \underline{\text{GR}})]$$

3. Use this updated position vector and the current time to find a new value of the gravitational acceleration:

$$\underline{\text{GR1}} = \underline{\text{ACCEL\_PERT\_ONORBIT}}\ (2, 0, 0, 0, 0, \underline{\text{R}}\text{ AV}, \underline{\text{V}}\text{ AV}, \text{T\_IMU}) - \text{EARTH\_MU}\ \underline{\text{R}}\text{ AV}/|\underline{\text{R}}\text{ AV}|^3$$

4. Advance the velocity vector by the average-g method:

$$\underline{\text{V}}\text{ AV} = \underline{\text{V}}\text{ AV} + \text{DTIME}\ [\underline{\text{AC}} + .5\ (\underline{\text{GR}} + \underline{\text{GR1}})]$$

B. Interface Requirements.

The input and output required are listed in Tables

4.6.1-1 and 4.6.1-2, respectively.

C. Processing Requirements

None.

D. Constraints

None.

E. Supplementary Information

A suggested implementation in the form of detailed flow charts is to be found in Appendix D.

TABLE 4.6.1-1 On-Orbit User Parameter State Propagation Input Parameters

DESCRIPTION	SYMBOL	INPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	SAMPLE RATE
Orbiter Velocity Vector after navigation updates	V_RESET	*	V	DP		Ft/sec	Filter Rate
Flag indicating the availability of filter updated states	FILT_UPDATE	*	D		OFF ON		Filter Rate
Flag indicating whether or not the current phase is a rendezvous phase	REND_NAV_FLAG	*	D		OFF ON		As Needed
Flag indicating whether or not the IMU velocities are to be used in propagation	USE_IMU_DATA	*	D		OFF ON		As Needed
Orbiter position vector after navigation updates	R_RESET	*	V	DP		Ft	UPP Rate
Time associated with currently read velocity counts from the IMU	T_IMU	*	F	DP		Sec	Filter Rate
Time associated with reserved reset state	T_RESET	*	F	DP		Sec	Filter Rate
Current selected accumulated IMU velocity	V_IMU_CURRENT	*	V	DP		Ft/sec	UPP Rate

* User parameter processing principal function input list.

TABLE 4.6.1-1 On-Orbit User Parameter State Propagation Input Parameters (cont'd)

DESCRIPTION	SYMBOL	INPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	SAMPLE RATE
Copy of V_CURRENT_FILT reserved for user parameter propagator reset	V_IMU_RESET	*	V	DP		Ft/sec	Filter Rate
Target position vector after navigation updates	R_TV_RESET	*	V	DP		Ft	Filter Rate
Target velocity vector after navigation updates	V_TV_RESET	*	V	DP		Ft/sec	Filter Rate

* User parameter processing principal function input list.

TABLE 4.6.1-2 On-Orbit User Parameter State Propagation Output Parameters

DESCRIPTION	SYMBOL	OUTPUT DESTINATION	TYPE	PRECISION	RANGE	UNITS	COMPUTATION RATE/SEC
State vector AVERAGE_G integration time step	DT_IMU	*	F	DP		Sec	User parameter propagator rate
Target vehicle's velociy vector	V_TARGET	*	V	DP		Ft/sec	User parameter propagator rate
Current orbiter position vector	R_AVGG	On-orbit user parameter calculations, *	V	DP		Ft	User parameter propagator rate
Time tag for current user parameter state vector	T_STATE	On-orbit user parameter calculations, *	F	DP		Sec	User parameter propagator rate
Orbiter current velocity vector	V_AVGG	On-orbit user parameter calculations, *	V	DP		Ft/sec	User parameter propagator rate
Current accumulated IMU velocity	V_IMU_OLD	*	V	DP		Ft/sec	User parameter propagator rate
Target vehicle's position vector	R_TARGET	*	V	DP		Ft	User parameter propagator rate

* User parameter processing principal function output list.

4.6.2 Onorbit User Parameter Calculations

This subfunction contains the software necessary to compute for display certain orbital elements representing the Shuttle's earth-relative position at either the current time or at a future time as selected by the crew. The orbital elements computed include: altitude above the reference ellipsoid, longitude, geodetic latitude and the longitude of the ascending node. These parameters will be computed during major modes 201 and 211 to support the Nav Monitor CRT display page.

A. Detailed Requirements. Certain flags will be tested to determine whether the crew wishes to have current or future parameters displayed. Whenever current parameters are desired, computations shall be performed cyclicly for the current user parameter state vector. Whenever future parameters are desired, computations shall be performed a single time for the predicted Shuttle state at the desired input time.

If the parameter, COMP_MODE, has a value of "CURRENT", then the orbital parameters are to be determined for the current time and the user parameter position and velocity vectors, as well as the associated time tag, are to be renamed for subsequent computations of orbital parameters:

$\underline{R}$_COMP = $\underline{R}$_AVGG

$\underline{V}$_COMP = $\underline{V}$_AVGG

T_COMP = T_STATE

If COMP_MODE has the value "PREDICT" and the flag DC_PREDICT = OFF, then either the crew has not yet entered the desired predict time or the computations were completed on a previous cycle and for either case no further computations are necessary.

If COMP_MODE has a value of "PREDICT" and the flag DO_PREDICT = ON the orbital parameters shall be computed for the input time, T_PREDICT. The Shuttle's position and velocity vectors at the future time shall be determined by calling the onorbit precision state prediction principal function (section 4.5.2) with inputs set to correspond to the "rapid precision" prediction method as follows:

CALL: ONORBIT_PREDICT

INLIST: 2,0,1,0,2,DT_PREDICT, R_AVGG, V_AVGG,
T_STATE, T_PREDICT

OUTLIST: R_COMP, V_COMP

The predict time is then to be renamed for subsequent computations of orbital parameters and the flag, DO_PREDICT, is to be set OFF:

T_COMP = T_PREDICT

DO_PREDICT = OFF

Next, for either of the two cases described above, orbital elements are to be computed. A matrix, valid at the time T_COMP, will be generated to transform M50 coordinates into earth-fixed coordinates:

M_TEMP_TXPOSE = EARTH_FIXED_TO_M50_COORD(T_COMP)^T

The Shuttle's position and inertial velocity vectors will then be transformed into earth-fixed coordinates:

R_EF = M_TEMP_TXPOSE R_COMP

V_EF = M_TEMP_TXPOSE V_COMP

The geodetic coordinates of the earth-fixed position vector shall then be determined by calling the EF_TO_GEODETIC subfunction:

CALL: EF_TO_GEODETIC

INLIST: R_EF

OUTLIST: LAT_GEOD, LONG, ALT

These parameters shall be converted for output and the longitude of the ascending node shall be determined:

ALTITUDE = ALT NAUTMI_PER_FT

LONGITUDE = LONG DEG_PER_RAD

LATITUDE = LAT_GEOD DEG_PER_RAD

ANG_MOM = R_EF X V_EF

ASC_NODE = ARCTAN2 (ANG_MOM, -ANG_MOM$_2$) DEG_PER_RAD

B. Interface Requirements. The input and output parameters for this subfunction are listed in Tables 4.6.2-1 and 4.6.2-2, respectively.

C. Processing Requirements. None.

D. Constraints. None

E. Supplementary Information. A suggested implementation of this subfunction in the form of a detailed flow chart can be found in Appendix D, NAV_MONITOR_SUPPORT.

TABLE 4.6.2-2: ONORBIT USER PARAMETER CALCULATIONS OUTPUT PARAMETERS

DESCRIPTION	SYMBOL	OUTPUT DESTINATION	TYPE	PRECISION	RANGE	UNITS	COMPUTATION RATE
Time for which orbital parameters are computed	T_COMP	*	F	DP		SEC	AS NEEDED
Flag which indicates whether or not computations have been completed when "future" parameters are requested	DO_PREDICT	ONORBIT UPP	BIT		ON OFF		0.5
Altitude of Shuttle above the reference ellipsoid	ALTITUDE	*	F	DP		NMI	0.5
Longitude of the Shuttle sub-vehicle point	LONGITUDE	*	F	DP		DEG	0.5
Geodetic latitude of the Shuttle sub-vehicle point	LATITUDE	*	F	DP		DEG	0.5
Longitude of the ascending node for the Shuttle orbit	ASC_NODE	*	F	DP		DEG	0.5

* onorbit user parameter processor principal function output list

TABLE 4.6.2-1: ONORBIT USER PARAMETER CALCULATIONS INPUT PARAMETERS

* onorbit user parameter processor principal function input list

DESCRIPTION	SYMBOL	INPUT SOURCE	TYPE	PRECISION	RANGE	UNITS	SAMPLE RATE
Indicates whether computations are to be performed for the Shuttle state at the current time or at a future time	COMP_MODE	*	CHAR	DP			0.5
Time for which future orbital parameters are to be computed	T_PREDICT	*	F	DP		SEC	0.5
Flag which indicates whether or not computations have been completed when "future" parameters are requested.	DO_PREDICT	ONORBIT UPP,*	BIT		ON OFF		0.5
Integration Step Size	DT_PREDICT	PREMISSION LOAD	F	DP		SEC	AS NEEDED
Shuttle M50 position vector at time T_PREDICT	R_COMP	*	V	DP		FT	AS NEEDED
Shuttle M50 velocity vector at time T_PREDICT	V_COMP	*	V	DP		FT/SEC	AS NEEDED
Feet to nautical mile conversion factor	NAUTMI_PER_FT	CONSTANT	F	DP		NMI/FT	0.5
Radian to degree conversion factor	DEG_PER_RAD	"	F	DP		DEG	0.5
Current Shuttle position vector	R_AVGG	UP ST PROP	V	DP		FT	0.5
Current Shuttle velocity vector	V_AVGG	"	V	DP		FT/SEC	0.5
Time tag for current user parameter state vector	T_STATE	"	F	DP		SEC	0.5

APPENDIX A

NAVIGATION VARIABLE NAMES AND

DESCRIPTIONS

VARIABLES LIST DEFINITIONS

<u>Code used for variable data type</u>

S:	scalar
V(n):	vector (dimension)
M(n):	square matrix (dimension)
INT:	integer
BIT:	bit
CHAR:	character
STR:	structure
ARR:	array

<u>Coordinate frame code and definition</u>

Body: (structural)	x: parallel to the longitudinal axis (positive aft)
	y: completes right-hand system
	z: perpendicular to the x-axis, positive upward
EF	Earth-fixed coordinate system
M50:	Mean of 50 reference coordinate system
RW: (runway coordinates)	x: down runway centerline in direction of landing
	y: completes right-hand system
	z: down, normal to ellipsoid
TD: (topodetic coordinates)	x: north
	Y: east
	z: down, normal to ellipsoid
UVW	Quasi-inertial, right-handed Cartesian coordinate system
	u: along vehicle position vector (radial)
	v: normal to u, in orbit plane (downtrack)
	w: out of orbit plane, uxv=w, (crosstrack)

C.5

APPENDIX A VARIABLE LIST

VARIABLE NAME	DATA TYPE	INITIAL VALUE	COORD FRAME	VARIABLE DESCRIPTION
A	ARR(4)	PAD		Array of coefficients required by the RK_GILL integrator
A	ARR(9,2)			Legendre functions array in gravitational acceleration calculation (local variable)
ALPHA	S			Angle of attack
ALT	S			Altitude above ellipsoid
AM	INT	0		Flag (ON) to indicate the use of the Adams-Moulton integration technique
AM_TABLE	ARR(8,7)	0	M50	Table of derivatives required by the Adams-Moulton integrator
ANGLES_AIF	CHAR	AUTO		AUTO/INHIBIT/FORCE switch associated with the currently enabled angles data set
ANNUAL_EFF	S	I LOAD		Variable used in K3 term of atmospheric density
AREA	S			Vehicle's cross-sectional area for DRAG acceleration calculations
A_RESID	V(3)		M50	Acceleration interpolated to a specified measurement time
A_SENS	V(3)		M50	Sensed acceleration at current time

APPENDIX A VARIABLE LIST (Continued)

VARIABLE NAME	DATA TYPE	INITIAL VALUE	COORD FRAME	VARIABLE DESCRIPTION
ATFL	INT			Flag controlling use or non-use of prestored attitude profile, average area, mass, and drag coefficient of orbiter or target vehicles
ATM	INT			Attitude mode flag, controls use or non-use of prestored attitude profile, average area, mass, and drag coefficient of orbiter or target vehicle
ATT_ARRAY	ARR			Time line array of attitude information (dimension 9 by TBD)
ATT_FLAG	INT			Flag indicating vehicle attitude mode
ATT_MODE	S	I LOAD		Acceleration function attitude mode flag
AUXILIARY	S			Intermediate variable in gravitational acceleration calculations
A1	S			Temporary variable used in transition matrix computation
A2	S			Temporary variable used in transition matrix computation
A3	S			Temporary variable used in transition matrix computation
A4	S			Temporary variable used in transition matrix computation
A5	S			Temporary variable used in transition matrix computation

APPENDIX A VARIABLE LIST (Continued)

VARIABLE NAME	DATA TYPE	INITIAL VALUE	COORD FRAME	VARIABLE DESCRIPTION
A6	S			Temporary variable used in transition matrix computation
A7	S			Temporary variable used in transition matrix computation
A8	S			Temporary variable used in transition matrix computation
A9	S			Temporary variable used in transition matrix computation
B	ARR(4)	PAD		Array of coefficients required by the RK_GILL integrator
B	V(19)			Measurement first partials with respect to the filter state
BETA	S			Angle of sideslip
B_TEMP	V(3)		M50	Temporary value of partial vecter (before rotation to current time)
BIAS_SENSOR	V(4)			Filter estimated sensor biases
BT_E_B	S			Variable used to store the value of the dot product of B and EB
C	ARR(4)	PAD		Array of coefficients used by the RK_GILL integrator
CD	S			Vehicle's drag coefficient for drag acceleration calculations

APPENDIX A VARIABLE LIST (Continued)

VARIABLE NAME	DATA TYPE	INITIAL VALUE	COORD FRAME	VARIABLE DESCRIPTION
CDA	V(NUM_CONF)	I LOAD		Constants used to model drag coefficient (additional corrective term)
CDEC1	S			Sine of solar right ascension
CDEC2	S			Variable used in K2 term of atmospheric density
CDF	V(NUM_CONF)	I LOAD		Constants used to model drag coefficient (frontal area)
CDN	V(NUM_CONF)	I LOAD		Constants used to model drag coefficient (top area correction)
CDS	V(NUM_CONF)	I LOAD		Constants used to model drag coefficient (side area correction)
C_EPS	S			Cosine of obliquity of ecliptic
CGAM1	S			Variable used in K2 term of atmospheric density
CGAM2	S			Variable used in K2 term of atmospheric density
C_INC	S	I LOAD		Cosine of inclination of lunar orbit plane on ecliptic
C_MN_AN	S			Variable used in K2 term of atmospheric density
C_MX_AN	S			Variable used in K2 term of atmospheric density

APPENDIX A VARIABLE LIST (Continued)

VARIABLE NAME	DATA TYPE	INITIAL VALUE	COORD FRAME	VARIABLE DESCRIPTION
COAS_ANGLES_EDIT OVERRIDE	BIT	OFF		Flag used (ON) to override the residual edit test for COAS angles data
COAS_ANGLES_STAT	BIT	OFF		Flag indicating (ON) that COAS angles data are to be processed for statisical display only
COAS_ENABLE	BIT	OFF		COAS angles ENABLE flag
COAS_MARK_NUM	S	0.0		COAS measurement mark counter
C_OM	S			Cosine of OMEGA
CONF_ARRAY	ARR(2,NUM_ CONF)	I LOAD		Configuration timeline
COR	V(7)			Temporary vector used in covariance matrix re-initialization
CORR_POWER_ 1	S	I LOAD		Variable used in K2 term of atmospheric density
CORR_POWER_2	S	I LOAD		Variable used in K2 term of atmospheric density
COS_PSI_1	S			Variable used in K2 term of atmospheric density
COS_PSI_2	S			Variable used in K2 term of atmospheric density
COS_SOL_RA	S			Cosine of solar right ascension

APPENDIX A VARIABLE LIST (Continued)

VARIABLE NAME	DATA TYPE	INITIAL VALUE	COORD FRAME	VARIABLE DESCRIPTION
COV_ACCEL_BODY_INIT	V(3)	I LOAD	BODY	Vector (3x1) of unmodeled acceleration bias error variances (body coordinate system)
COV_COR_OPS_2	V(7)	I LOAD		Vector (7x1) of correlation coefficients associated with the UVW standard deviations SIG_UVW_OPS_2, used for orbiter position/velocity covariance initialization
COV_COR_TV	V(7)	I LOAD		Vector (7x1) of correlation coefficients associated with the UVW standard deviations SIG_TV_UVW, used for target position/velocity covariance initialization
COV_COR_TV_UPDATE	V(7)	I LOAD		Vector of correlation coefficients associated with UVW standard deviations (SIG_TV_UPDATE) used for target vehicle position/velocity covariance initialization (ground update)
COV_COR_UPDATE	V(7)	I LOAD		Vector of correlation coefficients associated with UVW standard deviations (SIG_UPDATE) used for orbiter position/velocity covariance initialization (ground update)
C1	S			Scratch variable used in the mean conic partial calculation
C2	S			Scratch variable used in the mean conic partial calculation
CONST	S			Temporary variable used in transition matrix computation
C_TH	S			Cosine of THETA

APPENDIX A VARIABLE LIST (Continued)

VARIABLE NAME	DATA TYPE	INITIAL VALUE	COORD FRAME	VARIABLE DESCRIPTION
C1	S			Auxiliary variable used in F and G series computations and in Pines' method
C1	S			Cosine of prestored attitude Euler angle (local variable)
C2	S			Auxiliary variable used in F and G series computations and in Pines' method
C2	S			Cosine of prestored attitude Euler angle (local variable)
C3	S			Auxiliary variable used in Pines' variation of parameters method
C3	S			Cosine of prestored attitude Euler angle (local variable)
C4	S			Auxiliary variable used in Pines' variation of parameters method
C5	S			Auxiliary variable used in Pines' variation of parameters method
D	ARR(4)	PAD		Array of coefficients used by the RK_GILL integrator
$\underline{D}$	V(3)		M50	Acceleration due to atmospheric drag
DA_THRESHOLD	S			Threshold value for magnitude of sensed acceleration

APPENDIX A VARIABLE LIST (Continued)

VARIABLE NAME	DATA TYPE	INITIAL VALUE	COORD FRAME	VARIABLE DESCRIPTION
D_AUX	S			Dot product of velocity vector and perturbing acceleration
DAY_OF_YEAR	S			Number of current day in current year
DAY_ONE	S			Variable used in K3 term of atmospheric density
D_COE_PCT_ERR	S	I LOAD		Percent error in the drag coefficient
DELQ	S			Measurement residual
DELTAT_GO	S			Time interval between two positions in a conic (F and G series)
DELTAT	S			Time interval between two positions in a conic (F and G series)
DELTAT_T	S	0		Input integration step size for prediction or propagation
DERIV	ARR(7)	0	M50	Temporary storage for derivatives required for the Adams-Moulton integrator
D_FIN	S			Dot product of final position and velocity vectors, used in F and G series (conic solution)
DFL	INT			Flag indicating activation (1) or de-activation (0) of drag model (local variable)
DIAG	V(3)			Scratch vector

APPENDIX A VARIABLE LIST (Continued)

VARIABLE NAME	DATA TYPE	INITIAL VALUE	COORD FRAME	VARIABLE DESCRIPTION
DID_AUTO_UPDATE	BIT			Flag indicating (ON) that an auto update has been performed
D_IN	S	0		Dot product of the integrated initial position and velocity vectors
DISP_DELQ	V(4)	0		Display measurement residual for the I'th measurement type, I=1,4
DISP_SIG	V(4)	0		Display residual edit ratio for I'th measurement type, I=1,4
DIURN_EFF_1	S	I LOAD		Variable used in K2 term of atmospheric density
DIURN_EFF_2	S	I LOAD		Variable used in K2 term of atmospheric density
DIURN_EFF_3	S	I LOAD		Variable used in K2 term of atmospheric density
DIURN_EFF_4	S	I LOAD		Variable used in K2 term of atmospheric density
DIURN_EFF_5	S	I LOAD		Variable used in K2 term of atmospheric density
DIURN_EFF_6	S	I LOAD		Variable used in K2 term of atmospheric density
DM	INT	0		Flag to indicate choice of models for accelerations due to drag

APPENDIX A VARIABLE LIST (Continued)

VARIABLE NAME	DATA TYPE	INITIAL VALUE	COORD FRAME	VARIABLE DESCRIPTION
D_MN_AN	S			Difference in mean anomalies, used to solve Kepler's equation
DNM	S			Auxiliary variable in gravitational acceleration calculations
DO_AUTO_UPDATE	BIT	OFF		Flag indicating (ON) that an auto inflight update is to be performed
DO_COAS_ANGLES_NAV	BIT	OFF		On-off switch indicating (ON) that COAS angles data has been selected for processing
DO_COAS_ANGLES_NAV_LAST	BIT	OFF		On-off switch indicating (ON) that COAS angles data was selected for processing on the last filter cycle
D_ONE	S			Dot product of position and velocity vectors for transition matrix computation and F and G series
DO_RR_ANGLES	BIT	OFF		Flag indicating (ON) that rendezvous radar angles data are to be processed
DO_RR_ANGLES_NAV	BIT	OFF		On-off switch indicating (ON) that rendezvous radar angles data has been selected for processing
DO_RR_ANGLES_NAV_LAST	BIT	OFF		ON-off switch indicating (ON) that rendezvous radar angles data was selected for processing on the last filter cycle
DO_RRDOT_NAV	BIT	OFF		On-off switch indicating (ON) that rendezvous radar range and range rate data has been selected for processing

APPENDIX A VARIABLE LIST (Continued)

VARIABLE NAME	DATA TYPE	INITIAL VALUE	COORD FRAME	VARIABLE DESCRIPTION
DO_RRDOT_NAV_LAST	BIT	OFF		On-off switch indicating (ON) that rendezvous radar range and range rate data was selected for processing on the last filter cycle
DO_ST_ANGLES_NAV	BIT	OFF		On-off switch indicating (ON) that startracker angles data has been selected for processing
DO_ST_ANGLES_NAV_LAST	BIT	OFF		On-off switch indicating (ON) that startracker angles data was selected for processing on the last filter cycle
DT	S			Temporary storage for step-size used state vector propagation
D_TAU	S			Dot product of position vector and perturbing acceleration
DT_FILT	S			Interval over which to propagate the state vector
D_TWO	S			Dot product of position and velocity vectors for transition matrix computation and F and G series
DOY_EFF	V(38)	I LOAD		Array used in K3 term of atmospheric density
DT_FILT	S			Interval over which to propagate the covariance matrix
DTGO	S			Time interval over which state vector interpolation is to be performed
DT_ONORBIT_NAV	S	I LOAD		Sequencing time interval for onorbit navigation during onorbit coast phase

APPENDIX A VARIABLE LIST (Continued)

VARIABLE NAME	DATA TYPE	INITIAL VALUE	COORD FRAME	VARIABLE DESCRIPTION
DT_ONORBIT_PWRD_FLT	S	I LOAD		Sequencing time interval for onorbiting navigation during onorbit powered flight phase
DT_REND_NAV	S	I LOAD		Sequencing time interval for rendezvous navigation during rendezvous coast phase
DT_REND_PWRD_FLT	S	I LOAD		Sequencing time interval for rendezvous navigation during rendezvous powered flight phase
DT_REND_TPF_NAV	S	I LOAD		Sequencing time interval for rendezvous navigation during TPF stationkeeping phase
DT_STEP	S	0		Integration step size for prediction or propagation
D_TWO	S			Dot product of position and velocity vectors for transition matrix computation and F and G series
DV	V(3)		M50	Temporary storage for difference in accumulated IMU sensed velocities
DV_FILT	V(3)		M50	Difference between accumulated sensed IMU readings on present cycle and previous cycle
E	M(19)		VARY	Filter covariance matrix
EARTH_MU	S	I LOAD		Gravitational constant of the earth

APPENDIX A VARIABLE LIST (Continued)

VARIABLE NAME	DATA TYPE	INITIAL VALUE	COORD FRAME	VARIABLE DESCRIPTION
EARTH_POLE	V(3)	I LOAD	M50	Unit vector in direction of earth's axis of rotation
EARTH_RADIUS_EQUATOR	S	I LOAD		Earth equitorial radius
EARTH_RADIUS_GRAV	S	I LOAD		Earth radius used for gravitational acceleration calculations
EARTH_RATE	S	I LOAD		Earth's angular rotation rate
EB_COPY	V(19)			Covariance matrix times partials vector
EDIT_FLAG	INT			Four-valued switch (forced, processed, stat, off) used to indicate whether the filter processed sensor measurement data that was forced, auto-selected, or inhibited, or not processed
E_INIT	M(6)		M50	Filter covariance matrix (6 x 6) saved across a memory transition
ELLIPT	S	I LOAD		Earth ellipticity constant
EPSILON	S			Obliquity of the ecliptic
EPS_KEP	S			Tolerance for successive iterations in the solution of Kepler's equation
EPS_TIME	V(3)			Array of sensor-related tolerances for SV_INTERP

APPENDIX A VARIABLE LIST (Continued)

VARIABLE NAME	DATA TYPE	INITIAL VALUE	COORD FRAME	VARIABLE DESCRIPTION
EPS_VRB	S	I LOAD		Tolerance for Z-component of relative velocity vector in body coordinates
EPS1	S	I LOAD		Tolerance for Z local vertical body position acceptance
EPS2	S	I LOAD		Tolerance for X local vertical body position acceptance
EPS3	S	I LOAD		Tolerance for an inertial hold body position acceptance
EPS4	S	I LOAD		Tolerance for inertial with rate hold body position acceptance
ERR	S			Auxillary variable used in F and G series (conic solution) computations
E_TEMP	M(6)		M50	Temporary matrix (6 x 6) used for covariance reinitialization
EV	V(3)		BODY	Unit vector in the direction of the eigen-axis
EXP_SHAPE_FACTOR	V(NUM_CONF)	I LOAD		Exponential shaping factors for drag coefficient model
F	S			Closed form version of F time series
FACTOR	S			Secant of solar declination
FDOT	S			Closed form version of time derivative of F and G series

APPENDIX A VARIABLE LIST (Continued)

VARIABLE NAME	DATA TYPE	INITIAL VALUE	COORD FRAME	VARIABLE DESCRIPTION
FIFTY	M(3)			Transformation matrix EF to M50
FILT_UPDATE	BIT	OFF		Switch indicating (ON) that current navigation cycle is complete
FM1	S			Auxiliary variable (F-1.)
F1	S			Auxiliary variable in gravitational acceleration calculations
F2	S			Auxiliary variable in gravitational acceleration calculations
F3	S			Auxiliary variable in gravitational acceleration calculations
F4	S			Auxiliary variable in gravitational acceleration calculations
G	S			Term in F and G series (conic) respre-sentation (local variable)
$\underline{G}$	V(3)		M50	Gravitational acceleration
GD	INT			Flag specifying degree of gravitational acceleration model (local variable)
GDM1	S			Temporary variable G dot minus 1
GDOT	S			Closed form version of time derivative of F and G series
GD_TAU	S			Perturbation derivative of GDOT

APPENDIX A VARIABLE LIST (Continued)

VARIABLE NAME	DATA TYPE	INITIAL VALUE	COORD FRAME	VARIABLE DESCRIPTION
GEOMAG_DISTURB_CORRECT	S			Geomagnetic disturbance correction in atmospheric density calculation
GMD	INT			Flag indicating the degree of the gravitational potential model (local variable)
GM_DEG	S	I LOAD		Flag indicating degree of gravitational potential model
GMO	INT			Flag indicating the order of the gravitational potential model (local variable)
GM_DEG_LOW	INT	I LOAD		Lowest degree used in calls to the acceleration function (gravity model)
GMO	INT			Flag indicating the order of the gravitational potential model
GM_ORD	S	I LOAD		Flag indicating order of gravitational potential model
GM_ORD_LOW	INT	I LOAD		Lowest order of potential model in calls to the acceleration function
G_ _NEW	V(3)		M50	Orbiter acceleration vector
GO	INT			Flag indicating order of gravitational potential model (local variable)
GR_INT	V(3)		M50	Intermediate value of acceleration used in super-G integration
GR_NEW	V(3)		M50	Local value of modeled acceleration used super-G integrator

APPENDIX A VARIABLE LIST (Continued)

VARIABLE NAME	DATA TYPE	INITIAL VALUE	COORD FRAME	VARIABLE DESCRIPTION
G_TV	V(3)		M50	Target vehicle total acceleration vector (M1950)
G_TV_LAST	V(3)		M50	Target vehicle total acceleration vector, last value
HANG	S			Angular displacement about the eigen-axis
HORIZ	S			Filter estimate of the horizontal angle measurement
I	INT			Counter
IATM	INT			Attitude mode flag, controls use or non-use of prestored attitude profile, average area, mass, and drag coefficient of orbiter or target vehicle
IDM	INT			Flag indication the activation (1) or de-activation (0) of the drag model (local variable)
ID_MATRIX_3X3	M(3)	I LOAD		Three by three identity matrix
IDRAG	INT			Drag mode flag used by the state propagation
IGD	INT			Temporary storage of indicator of potential degree, used in state propagator
IGO	INT			Temporary storage of indicator of potential model order used in state propagator

APPENDIX A VARIABLE LIST (Continued)

VARIABLE NAME	DATA TYPE	INITIAL VALUE	COORD FRAME	VARIABLE DESCRIPTION
I_N	V(3)		M50	An arbitrary coordinate unit axis expressed in mean of 1950
INTERM	V(3)			Vector of intermediate quantities in lunar ephemeris calculation
I_RHO	V(3)	0.0	M50	Unit line of sight vector
IVENT	INT			Temporary value of venting mode flag, used in state propagator
IVM	INT			Flag indicating activation (1) or de-activation (0) of the venting and RCS uncoupled thrusting model (local variable)
J	INT			Counter
K	INT			Integer counter
K_RESID_EDIT	S	I LOAD		Residual edit scale factor (squared)
K1	S			Solar radiation term in atmospheric density
K2	S			Diurnal bulge term in atmospheric density
K3	S			Semi-annual effect term in atmospheric density
K4	S			Geomagnetic effect term in atmospheric density
L	INT			Integer counter

APPENDIX A VARIABLE LIST (Continued)

VARIABLE NAME	DATA TYPE	INITIAL VALUE	COORD FRAME	VARIABLE DESCRIPTION
M	M(3)			General matrix used as temporary array
MAGN_EFF	S	I LOAD		Variable used in K4 term of atmospheric density
MANUAL_EDIT_OVERRIDE	INT			Copy of the manual edit override flag of the sensor data type currently being processed that is sent to the filter
MAX_NUM_VENT	INT	I LOAD		Maximum number of vent sources allowable
MAX_DENS_ANGLE	S	I LOAD		Angle to earth's atmospheric bulge (Russian density model)
MIN_DENS_ANGLE	S	I LOAD		Angle to reference point in atmosphere (Russian density model)
$M\_M50BODY_K$	M(3)			Transformation matrix from M50 to body system (K represents the selected matrix by IMU-RM)
MOON_AUXIL	V(3)			Vector of auxiliary values in computation of lunar ephemeris
MOON_CONST	V(3)	I LOAD		Vector of constants for calculation of THETA
MOON_PARAM_FIRST	V(3)	I LOAD		Coefficient of first order term in development of MOON_AUXIL
MOON_PARAM_ZERO	V(3)	I LOAD		Constant term in development of MOON_AUXIL
MS_DELQ	S			Variance of computed sensor

APPENDIX A VARIABLE LIST (Continued)

VARIABLE NAME	DATA TYPE	INITIAL VALUE	COORD FRAME	VARIABLE DESCRIPTION
M_TEMP	M(3)			Temporary 3 x 3 matrix (local variable)
N_ACCEPT	V(4)	0		Counter for the number of data marks, for the I'th measurement type, which have been utilized to update the navigation state vector, I=1,4
NIGHT_PROF_1	S	I LOAD		Constant used in night time altitude-density profile
NIGHT_PROF_2	S	I LOAD		Constant used in night time altitude-density profile
NIGHT_PROF_3	S	I LOAD		Constant used in night time altitude-density profile
NOISE_R	S			Noise disturbance added to position element variances
NOISE_RV	S			Noise disturbance added to position - velocity correlation variances
N_REJECT	V(4)	0		Counter for the number of data marks, for the I'th measurement type, which have been edited by the navigation filter, I=1,4
N_STEPS	INT	0		Number of integration steps in the prediction or propagation interval
NUM_ATT	INT	I LOAD		Number of data sets contained in pre-stored attitude profile
NUM_CONF	INT	I LOAD		Number of configurations of orbiter for drag acceleration calculations

ORIGINAL PAGE IS
OF POOR QUALITY

APPENDIX A VARIABLE LIST (Continued)

VARIABLE NAME	DATA TYPE	INITIAL VALUE	COORD FRAME	VARIABLE DESCRIPTION
NUM_VENT	V(MAX_NUM_VENT)	I LOAD		Number of time points in the vent time line for each vent
N1	INT			Integer counter (local variable)
OMEGA	S			Longitude of ascending node of lunar orbit on ecliptic
OMEGA	V(19)			Kalman gains vector
OM_1	S	I LOAD		Coefficient of first order term in development of OMEGA
OM_2	S	I LOAD		Constant term in development of OMEGA
ONEMRIN	S			Auxiliary variable used in solving Kepler's equation (F and G series)
OPS_2_OR_8_INITIALIZE COMPLETE	SIGNAL			Signal to MSC indicating (COMPLETE) initialization of user parameter state propagation quantities is complete
OV_UPLINK	BIT	OFF		Flag set by ground uplink processor indicating (ON) that an orbiter vehicle state vector has been uplinked
P	S	0		Local variable used in the RK-GILL integrator
P	V(3)		M50	Perturbing acceleration (Pines' method)
PHI	M(9)			State transition matrix for Space Shuttle from state at previous filter time to state at current time

ORIGINAL PAGE IS OF POOR QUALITY

VARIABLE NAME	DATA TYPE	INITIAL VALUE	COORD FRAME	VARIABLE DESCRIPTION
PHI_MC	M(9)			Patch transition matrix
PHI_PATCH	M(3)			Transition matrix for converting from time of measurement to current time (for Space Shuttle)
PHI_REND	M(10)			State transition matrix for target vehicle from current state to state computed at measurement time
PHI_REND_PATCH	M(3)			Transition matrix for converting from time of measurement to current time (for target vehicle)
PREC_STEP	S	I LOAD		Integration step size for precision prediction
PWRD_FLT_NAV	BIT	OFF		Flag indicating use of powered flight propagator (ON), or coasting flight propagator (OFF)
Q	ARR(7)	0		Local array used in the RK-GILL integrator
Q_HORIZ	S			Measurement from horizontal measurement sensor
Q_PRIME	BIT	0.0		Computed measurement
Q_RR_SHFT	S			Rendezvous radar shaft measurement angle
Q_RR_TRUN	S			Rendezvous radar trunnion measurement angle
Q_VERT	S			Vertical measurement from sensor

APPENDIX A VARIABLE LIST (Continued)

VARIABLE NAME	DATA TYPE	INITIAL VALUE	COORD FRAME	VARIABLE DESCRIPTION
R	V(3)		M50	Temporary M50 position vector
RAD_EFF	S	I LOAD		Variable used in K1 term of atmospheric density
R_CHECK_PT	V(3)		M50	Orbiter position vector (M50) saved via CHECKPOINT specialist function
RCS	V(3)		BODY	Acceleration vector due to RCS thrusting
RCS_BBQ	V(3)	I LOAD	BODY	Uncoupled thrusting acceleration due to an inertial with rate hold
RCS_INH	V(3)	I LOAD	BODY	Uncoupled thrusting acceleration due to an inertial hold
RCS_XLV	V(3)	I LOAD	BODY	Uncoupled thrusting acceleration due to an X-local-vertical hold
RCS_ZLV	V(3)	I LOAD	BODY	Uncoupled thrusting acceleration due to the Z local vertical body position
R_EF	V(3)		EF	Position vector in earth fixed coordinates
REF_AREA	V(I)	I LOAD		Average cross-sectional areas of orbiter (I=1) and target vehicle (I=2)
REF_CD	V(I)	I LOAD		Average drag coefficients of orbiter (I=1) and target vehicle (I=2)
REF_MASS	V(I)	I LOAD		Reference masses of orbiter (I=1) and of target vehicle (I=2)

APPENDIX A VARIABLE LIST (Continued)

VARIABLE NAME	DATA TYPE	INITIAL VALUE	COORD FRAME	VARIABLE DESCRIPTION
REND_NAV_FLAG	BIT	OFF		Flag indicating whether navigation-rendezvous in operation (ON), or navigation-onorbit in operation (OFF)
REND_STEP	S	I LOAD		Step size used by the precision propagator during rendezvous
RESID_TEST	S			Scaled value of variance for comparison with measurement deviation squared ($DELQ^2$)
R_FILT	V(3)		M50	Orbiter position vector (M50)
R_FILT_INIT	V(3)		M50	Orbiter position vector saved across memory reconfiguration and used for navigation initialization
R_FIN	V(3)	0	M50	Orbiter or target position vector at T_FIN
R_FIN_INV	S			Reciprocal of the magnitude of the final position vector (F and G series)
R_GND	V(3)		M50	Uplinked orbiter position vector (M1950)
RHO	S			Atmospheric density
RHO_PLANE	V(3)		M50	In plane component of line of sight
R_IN	S	0		Absolute value of the integrated initial position vector
R_IN	V(3)		M50	Position vector at the beginning of a time interval (F and G series)

APPENDIX A VARIABLE LIST (Continued)

VARIABLE NAME	DATA TYPE	INITIAL VALUE	COORD FRAME	VARIABLE DESCRIPTION
R_INV	S			Reciprocal of magnitude of position vector
R_IN_AUX	S			Auxiliary variable used in Pines' variation of parameters calculations
R_IN_INV	S			Reciprocal of the magnitude of the integrated initial position vector (F and G series)
R_IN_TAU	S			Auxiliary variable used in Pines' method
R_-LAST	V(3)		M50	Position vector of orbiter at the end of the last filter cycle
RNG_DATA_GOOD	BIT	OFF		Range data good
RO_N	S			Distance term in gravitational acceleration calculations
R _ONE	V(3)		M50	Position vector at the beginning of an interpolation interval
R_ONE_INV	S			Inverse of magnitude of a position vector
RO_ZERO	S			Distance term in gravitational acceleration calculations
RR_ANGLE DATA_GOOD	BIT			Flag indicating processable data from the rendezvous radar angle measurements
RR_ANGLE_MARK_NUM	S	0.0		Rendezvous-radar angle (shaft + trunnion) mark counter

ORIGINAL PAGE IS OF POOR QUALITY

APPENDIX A VARIABLE LIST (Continued)

VARIABLE NAME	DATA TYPE	INITIAL VALUE	COORD FRAME	VARIABLE DESCRIPTION
RR_ANGLES_EDIT_OVERRIDE	INT			ON-OFF switch used (ON) to override the automatic editing of rendezvous radar angles data
RR_ANGLES_ENABLE	BIT	OFF		Rendezvous radar angles ENABLE flag
RR_ANGLES_STAT	BIT	OFF		Flag indicating (ON) that rendezvous radar angles data are to be processed for statistical display only
RRDOT_EDIT_OVERRIDE	BIT	OFF		Flag used (ON) to override the residual edit test for rendezvous radar and range rate data
RRDOT_MARK_NUM	S	0.0		Rendezvous radar range-range rate measurement mark counter
RRDOT_STAT	BIT	OFF		Flag indicating (ON) that rendezvous radar range and range rate data are to processsed for statistical display only
R_RESET	V(3)		M50	Orbiter vehicle position vector after all navigation updates, reserved for reset of user parameter state propagator position vector
R_RESID	V(3)		M50	M1950 orbiter position vector interpolated to measurement time
R_RHO	V(3)		M50	Line of sight
R_RHO_MAG	BIT	0.0		Length of line of sight vector

APPENDIX A VARIABLE LIST (Continued)

VARIABLE NAME	DATA TYPE	INITIAL VALUE	COORD FRAME	VARIABLE DESCRIPTION
R _SUP	V(3)		M50	Position vector updated by the super-G integrator
R _TV	V(3)	I LOAD	M50	M1950 target vehicle position vector
R _TV_GND	V(3)		M50	Uplinked M1950 target vehicle position vector at T_TV_GND
R _TV_LAST	V(3)		M50	Target vehicle position vector, last value
R _TV_RESET	V(3)		M50	Target vehicle position vector after all navigation updates, reserved for reset of user parameters state propagator position vector
R _TWO	V(3)		M50	Position vector at the end of an interpolation interval
R_TWO_INV	S			Inverse of the magnitude of R _TWO
S	M(6)			Disturbance matrix (9X9) for Space Shuttle covariance propagation
SA	S			Square of sine of angle of attack
SB	S			Absolute value of the sine of the sideslip angle
SDEC	S			Sign of solar declination
SENSOR_BIAS	V(4)		M50	General systematic sensor biases part of state vector

APPENDIX A VARIABLE LIST (Continued)

VARIABLE NAME	DATA TYPE	INITIAL VALUE	COORD FRAME	VARIABLE DESCRIPTION
SENSOR_DELQ	V(4)			
SENSOR_EDIT	ARRAY(CHAR)			Five valued parameter defining use of the I'th measurement data by the navigation filter, I=1,4. ON- rejected by the residual edit test OFF- no processing attempted PROCESSED - accepted by residual edit test and used to update state vector STAT - used to generate display parameters FORCED - used to update state vector as a result of manual edit override
SENSOR_ID	INT			Identifier of the sensor measurement being processed, used in state vector interpolation
SENSOR_RESID	V(4)	0		Measurement residual for the I'th measurement type, I=1,4
SENSOR_RESID_TEST	V(4)	0		Value of the criterion used in the navigation filter for residual edit test for the I'th measurement type, I=1,4
S_EPS	S			Sine of obliquity of ecliptic
SEQ_ACCEPT	V(4)	0		Number of sequential sensor marks, for the I'th measurement type, processed by the navigation filter, I=1,4
SEQ_REJECT	V(4)	0		Number of sequential sensor marks, for the I'th measurement type, edited by the navigation filter, I=1,4

VARIABLE NAME	DATA TYPE	INITIAL VALUE	COORD FRAME	VARIABLE DESCRIPTION
SGAM1	S			Variable used in K2 term of atmospheric density
SGAM2	S			Variable used in K2 term of atmospheric density
SHFT	S			Estimate of the rendezvous radar shaft measurement
SIG	V(6)		UVW	Temporary vector used in covariance re-initialization
SIT_RR_RNG	S	0.0		One sigma value of the rendezvous radar range
SIG_TV_UPDATE	V(6)	I LOAD	UVW	Vector of standard deviations for target vehicle position/velocity covariance initialization (ground update)
SIG_TV_UVW	V(6)	I LOAD	UVW	Vector (6X1) of standard deviations (UVW) for target vehicle position/velocity covariance initialization
SIG_UPDATE	V(6)	I LOAD	UVW	Vector of standard deviations for orbiter position/velocity covariance initialization (ground update)
SIG_UVW_OPS_2	V(6)	I LOAD	UVW	Vector (6X1) of standard deviations (UVW) for orbiter position/velocity covariance initialization

APPENDIX A VARIABLE LIST (Continued)

VARIABLE NAME	DATA TYPE	INITIAL VALUE	COORD FRAME	VARIABLE DESCRIPTION
S_INC	S	I LOAD		Sine of inclination of lunar orbit plane on ecliptic
SIN_SOL_RA	S			Sine of solar right ascension
SLOPE_SIG_RR_RNG	S	0.0		Slope used to compute the one sigma value of the rendezvous radar
SMA	S			Semi-major axis of conic
S_MN_AN	S			Variable used in K2 term of atmospheric density
S_MX_AN	S			Variable used in K2 term of atmospheric density
SOL_AUXIL	V(4)			Orbital elements of the sun
SOL_LONG	S			Longitude of the sun
SOL_PARAM_FIRST	V(4)	I LOAD		Rate of change of the orbital elements of the sun
SOL_PARAM_ZERO	V(4)	I LOAD		Orbital elements of the sun at the beginning of the year
SOL_RAD_EMIT_CORRECT	S			Solar radiation correction in atmospheric density calculation
SOL_TRUE_ANOM	S			True anomaly of the sun
S_OM	S			Sine of OMEGA

APPENDIX A VARIABLE LIST (Continued)

VARIABLE NAME	DATA TYPE	INITIAL VALUE	COORD FRAME	VARIABLE DESCRIPTION
SQ	S			Scalar part of quaterion used in attitude matrix determination
SQR_EMU	S			Square-root of EARTH_MU, used in onorbit pred/prop integration (Pines') method
S_ REND	M(10)			Disturbance matrix (10X10) for rendezvous target and sensor biases covariance propagation
S_S_L	S			Sine of solar longitude
ST_ANGLES_EDIT_OVERRIDE	BIT	OFF		Flag used (ON) to override the residual edit test for star tracker angles data
ST_ANGLES_STAT	BIT	OFF		Flag indicating (ON) that star tracker angles data are to be processed for statistical display only
ST_ ENABLE	BIT	OFF		Star tracker angles ENABLE flag
S_TH	S			Sine of THETA
ST_MARK_NUM	S	0.0		Star tracker measurement mark counter
STAT_FLAG	INT			Copy of the stat-flag associated with the measurement type currently being processed
S0	S			Auxiliary variable used in F and G series computations
S1	S			Auxiliary variable used in F and G series computation and in Pines' method

VARIABLE NAME	DATA TYPE	INITIAL VALUE	COORD FRAME	VARIABLE DESCRIPTION
T_ALIGN	S	I LOAD		Time of last IMU alignment
T_ANGLES	S			Time tag for the angle type measurements
TARG_VEC_AVAIL	BIT	I LOAD		Flag indicating (ON) the availability of a target vehicle state vector and time tag for reinitialization purposes
TAU_COAS_ANGLES	V(2)	I LOAD		Time constant for the COAS angles sensor
TAU_RR_ANGLES	V(2)	I LOAD		Correlation time constant for the rendezvous radar angle measurements
TAU_RRDOT	V(2)	I LOAD		ECRV correlation time vector for rendezvous range and range rate
TAU_SENS	V(4)			General correlation time constant for sensors
TAU_ST_ANGLES	V(2)	I LOAD		Correlation time constant for startracker measurements
TAU_VENT	V(3)	I LOAD		Correlation time for body venting
T_CHECK_PT	S			Time tag of orbiter state vector saved via CHECKPOINT specialist function
T_CUR	S	0		Current integration time within the predictor or propagator
T_CURRENT_FILT	S			Time of current filter state vector
T_DIF	S			Time difference over which V_IMU_DIF is computed

VARIABLE NAME	DATA TYPE	INITIAL VALUE	COORD FRAME	VARIABLE DESCRIPTION
T_TEMP	V(3)	0.		A temporary scratch variable
T_FIN	S	0.		Final time at end of prediction or propagation
T_GND	S			Uplinked time tag of orbiter state vector (R _GND,V _GND)
THETA	S	-		Angle from mean ascending node of lunar orbit to the moon (local variable)
THETA	S			Difference in eccentric anomaly
THETA_COR	S			Correction to THETA in the solution of Kepler's equation
T_IN	S	0.		Initial time input for onorbit prediction or propagation
T_INITIAL	S	-		Attitude mode switching time
T_LAST_FILT	S			Time tag of V _LAST_FILT, & of filter state at last navigation cycle
T_LAST_FILT_INIT	S			Time tag of navigation initialization data carried across memory reconfiguration
TOT_ACC	V(3)		M50	Vector of orbiter total acceleration (M1950)
TOT_ACC_LAST	V(3)		M50	Value of TOT_ACC at the end of the previous cycle
T_REND_RADAR	S			Time at which the rendezvous radar is "snapped"

VARIABLE NAME	DATA TYPE	INITIAL VALUE	COORD FRAME	VARIABLE DESCRIPTION
T_RESET	S			Time associated with reserved reset state
T_RESID	S			Time tag of interpolated state vector
TRUN	S			Estimate of the rendezvous radar trunnion measurement
T_STOR	S	0.		Initial time of each Runge-Kutta integration step
T_TV	S			Time tag of target vehicle state vector
T_TV_GND	S			Uplinked target state time tag
T_TWO	S			Time tag of state at end of interpolation interval
TV_UPLINK	BIT	OFF		Flag set by ground uplink processor indicating (ON) that a target vehicle state vector has been uplinked
T1	S			Time since the beginning of the year, in Julian Centuries
U_M	V(3)		SENSOR AXES	Line of sight in sensor system
UR	V(3)		EF	Unit earth fixed position vector
U_RDOT	V(3)	0.0	M50	
UR_MOON	V(3)		M50	Earth to moon unit vector

VARIABLE NAME	DATA TYPE	INITIAL VALUE	COORD FRAME	VARIABLE DESCRIPTION
UR_SUN	V(3)		M50	Earth to sun unit vector
USE_IMU_DATA	BIT	OFF		Flag indicating usage of IMU data (ON) by powered flight propagator
USE_MEAS_DATA	BIT	ON		Flag indicating the use (ON) or non-use (OFF) of external measurement data (used for inhibiting filter data processing during burns and burn-targeting regions)
V	V(3)		M50	Temporary M1950 velocity vector
VAR	S			Copy of the variance associated with the measurement currently being processed
VAR_ACC_QUANT	S	I LOAD		Accelerometer quantization error variance
VAR_COAS_ANGLES	V(2)	I LOAD		
VAR_COAS_ANGLES_DT	V(2)	I LOAD		
VAR_HORIZ	S			Variance of the horizontal measurement sensor
VAR_IMU_ALIGN	V(3)	I LOAD		Variance of IMU time of alignment
VAR_IMU_DRIFT	V(3)	I LOAD		Variance contribution of IMU drift
VAR_RR_ANGLES	V(2)	I LOAD		Value used to initialize the covariance matrix diagonals associated with the rendezvous radar angles sensor biases
VAR_RR_ANGLES_DT	V(2)	I LOAD		Variance of the rendezvous radar angles measurements sensor biases

APPENDIX A VARIABLE LIST (Continued)

VARIABLE NAME	DATA TYPE	INITIAL VALUE	COORD FRAME	VARIABLE DESCRIPTION
VAR_RRDOT	V(2)	I LOAD		Initial value for the covariance matrix diagonal associated with the rendezvous radar range and range rate sensor biases
VAR_RRDOT_DT	V(2)	I LOAD		Variance of the rendezvous radar range and range rate sensor biases
VAR_RR_RNG_MIN	S	0.		Minimum value of the rendezvous radar variance
VAR_SENS_DT	V(4)			General bias variance vector for the current sensor set
VAR_SHFT	S	I LOAD		Variance of the rendezvous radar shaft angle
VAR_ST_ANGLES	V(2)	I LOAD		Initial startracker angle bias variance terms for the covariance matrix
VAR_ST_ANGLES_DT	V(2)	I LOAD		The filter gain variance for the startracker angle biases
VAR_TRUN	S	I LOAD		Variance of the rendezvous radar trunnion angle
VAR_UNMOD_ACC_DT	S	I LOAD		Variance of unmodeled acceleration times scale time
VAR_VENT_DT	V(3)	I LOAD		Variance of body venting variables
VAR_VERT	S	I LOAD		Vertical measurement variance

APPENDIX A VARIABLE LIST (Continued)

VARIABLE NAME	DATA TYPE	INITIAL VALUE	COORD FRAME	VARIABLE DESCRIPTION
V_CHECK_PT	V(3)		M50	Orbiter velocity vector (M50) saved via CHECKPOINT specialist function
V_CURRENT_FILT	V(3)		M50	Total accumulated IMU sensed velocity
VEH_MASS	S			Mass of vehicle for drag acceleration calculations
VENT	V(3)		M50	Acceleration due to venting and uncoupled RCS thrusting
VENT_ARRAY	ARR	I LOAD		Time line of the vent states for the major vents
VENT_DEP_RCS	ARR(3, MAX_NUM_VENT)	I LOAD	BODY	Uncoupled thrusting accelerations which are vent dependent
VENT_MODE_NAV	INT	I LOAD		Flag which activates (1) or de-activates (0) the venting & RCS uncoupled thrusting models
VENT_TABLE	ARR (3, MAX_NUM_VENT)	I LOAD	BODY	Acceleration vectors for the major vents
VENT_THRUST_BIAS	V(3)	I LOAD	BODY	Vector of unmodeled acceleration bias errors (body-fixed coordination system)
VFL	INT			Flag indicating activation (1) or de-activation (0) of venting & RCS uncoupled thrusting models (local variable)
V_LAST	V(3)		M50	Velocity vector of orbiter at end of the last filter cycle

APPENDIX A VARIABLE LIST (Continued)

VARIABLE NAME	DATA TYPE	INITIAL VALUE	COORD FRAME	VARIABLE DESCRIPTION
V_REL_BODY	V(3)		BODY	Orbiter's velocity relative to atmosphere in body coordinates
VERT	S			Filter estimated vertical angle for angle measurement
V_FILT	V(3)		M50	Orbiter velocity vector (M50)
V_FILT_INIT	V(3)		M50	Orbiter velocity vector saved across memory reconfiguration and used for navigation initialization
V_FIN	V(3)	0	M50	Orbiter or target velocity vector at T_FIN
V_GND	V(3)		M50	Uplinked orbiter velocity vector (M1950)
V_IMU_DIF	V(3)		M50	Difference in current and past accumulated sensed IMU velocities, used in state vector interpolation (local variable)
V_IMU_RESET	V(3)		M50	Copy of T_CURRENT_FILT reserved as velocity count at start of extrapolation interval when user parameter state propagator is reset
V_IN	V(3)	0	M50	Orbiter or target velocity vector at T_IN
V_LAST_FILT	V(3)		M50	Total accumulated IMU sensed velocity (M50)
V_LAST_FILT_INIT	V(3)		M50	Total accumulated IMU velocity saved across memory reconfiguration for navigation initialization
VM	INT	0		Flag to indicate which venting model is to be used

APPENDIX A VARIABLE LIST (Continued)

VARIABLE NAME	DATA TYPE	INITIAL VALUE	COORD FRAME	VARIABLE DESCRIPTION
V_ONE	V(3)		M50	Velocity vector at the beginning of a time interval, used to generate a transition matrix
VQ	V(3)		BODY	Vector part of quaternion used in attitude matrix determination
V_R	V(3)		M50	Velocity of vehicle relative to atmosphere
V_RESET	V(3)		M50	Orbiter vehicle velocity vector after all navigation updates reserved for reset of user parameters state propagator velocity vector
V_RESID	V(3)		M50	Mean of 1950 velocity vector interpolated to a measurement time
V_SUP	V(3)		M50	Velocity vector updated by the super-G integrator
V_TV	V(3)	I LOAD	M50	M1950 target vehicle velocity vector
V_TV_LAST	V(3)		M50	Target vehicle velocity vector, last value
V_TV_GND	V(3)		M50	Uplinked M1950 target vehicle velocity vector at T_TV_GND
V_TV_RESET	V(3)		M50	Target vehicle velocity vector after all navigation updates, reserved for reset of user parameters state propagator velocity vector

VARIABLE NAME	DATA TYPE	INITIAL VALUE	COORD FRAME	VARIABLE DESCRIPTION
V_TV_RESID	V(3)	0.0	M50	Velocity vector of target vehicle at time of measurement
V_TWO	V(3)		M50	Velocity vector at the end of a time interval, used to generate a transition matrix
WBR	V(3)		BODY	IMU derived body rate in radians/second
X	ARR(6)	0	M50	Temporary array for the Shuttle or target state vector
XN	ARR(7)	0	M50	Array of integrated initial conditions for onorbit prediction and propagation
ZETA_IMAG	V(9)			Longitude term in gravitational acceleration calculations
ZETA_REAL	V(9)			Longitude term in gravitational acceleration calculations
ZONAL	V(8)	I LOAD		Zonal harmonics coefficients

APPENDIX B

NAVIGATION SEQUENCER PRINCIPAL FUNCTION AND NAVIGATION PROCESSING PRINCIPAL FUNCTIONS FLOW CHARTS

CONTENTS

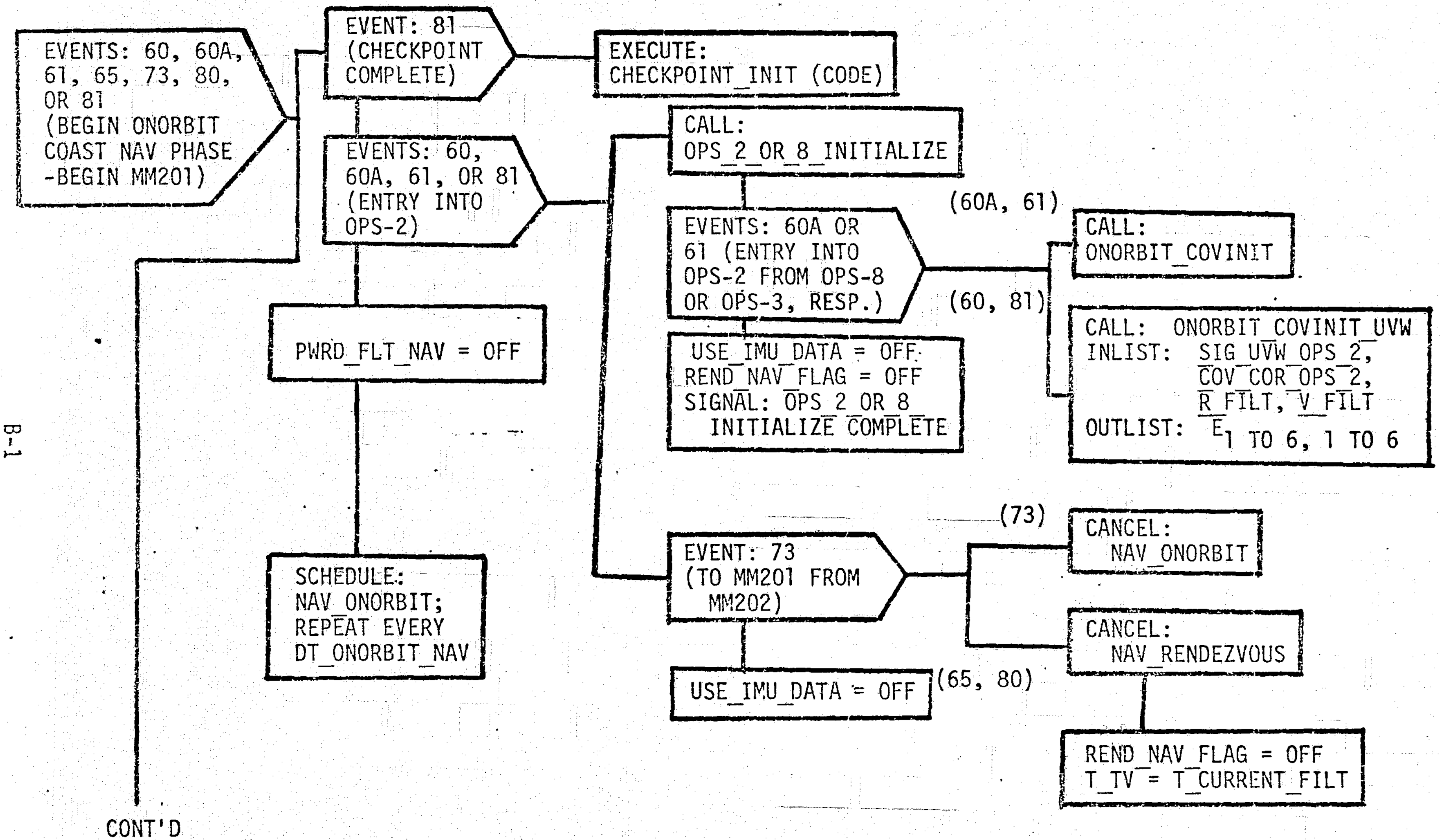
SUBJECT	PAGE

On-Orbit Navigation Principal Function (cont'd)

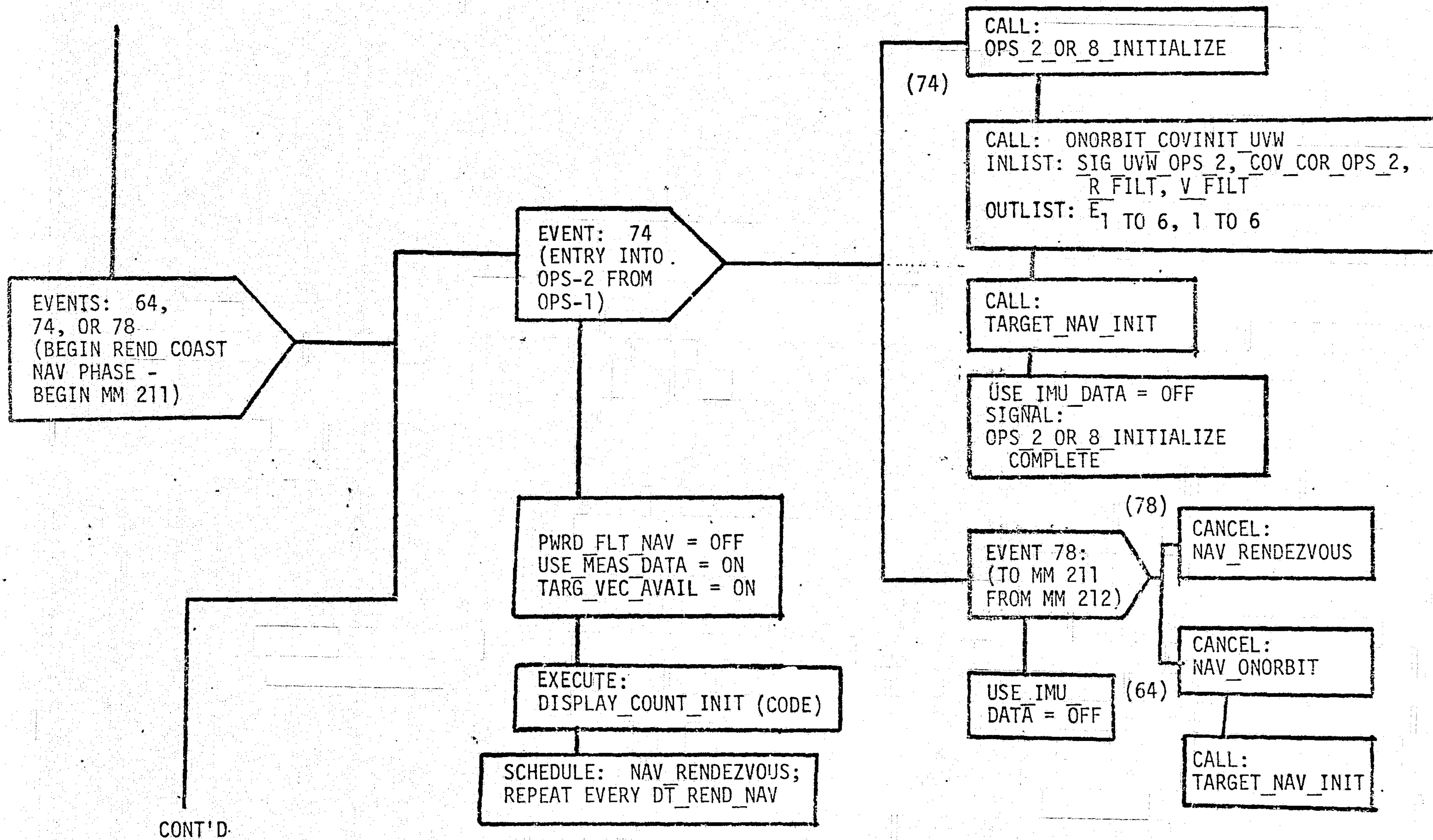
Rendezvous Navigation Principal Function

SUBJECT	PAGE
Rendezvous Navigation Principal Function (cont'd)	

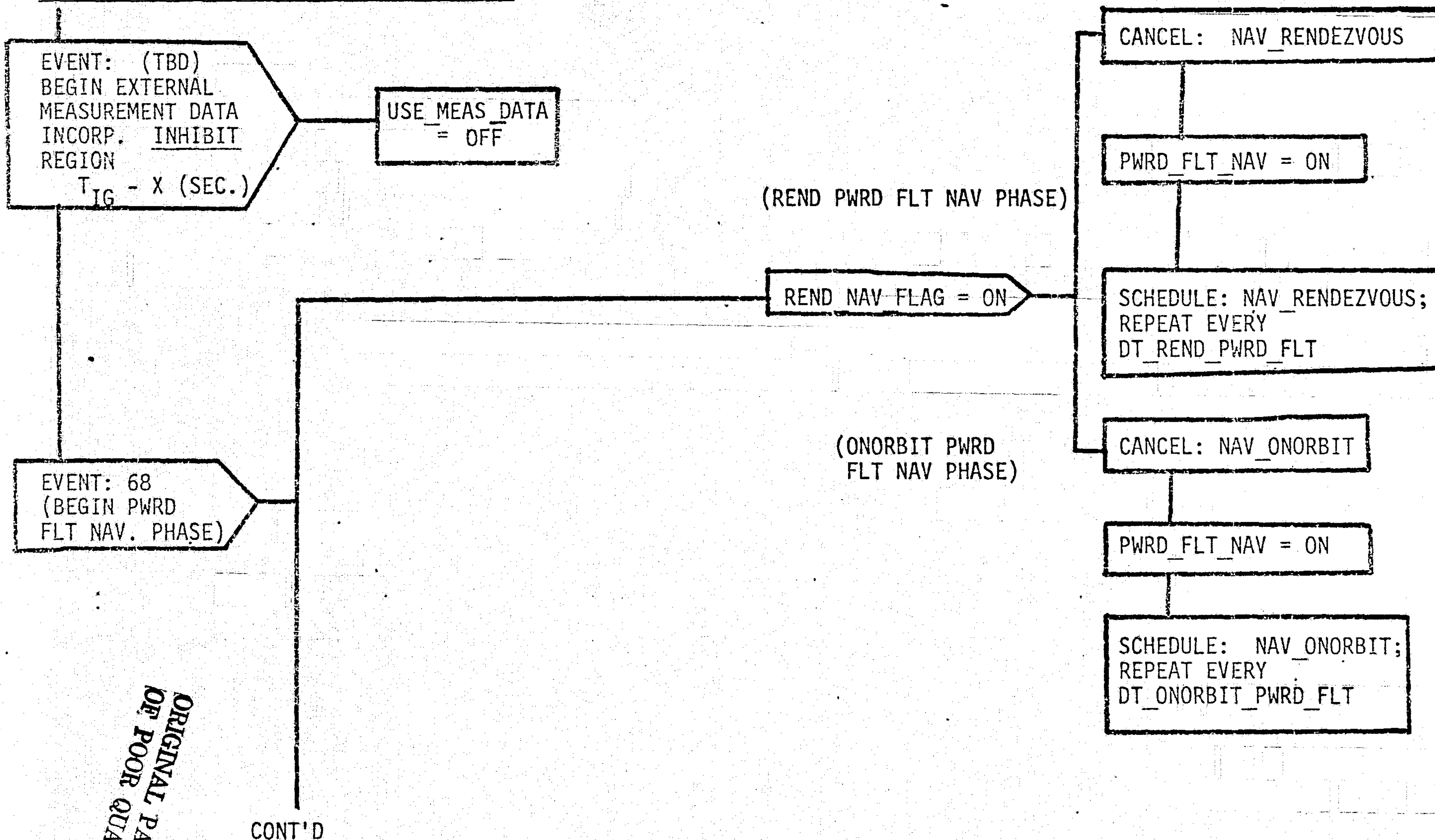
ONORBIT_REND_NAV_SEQUENCER



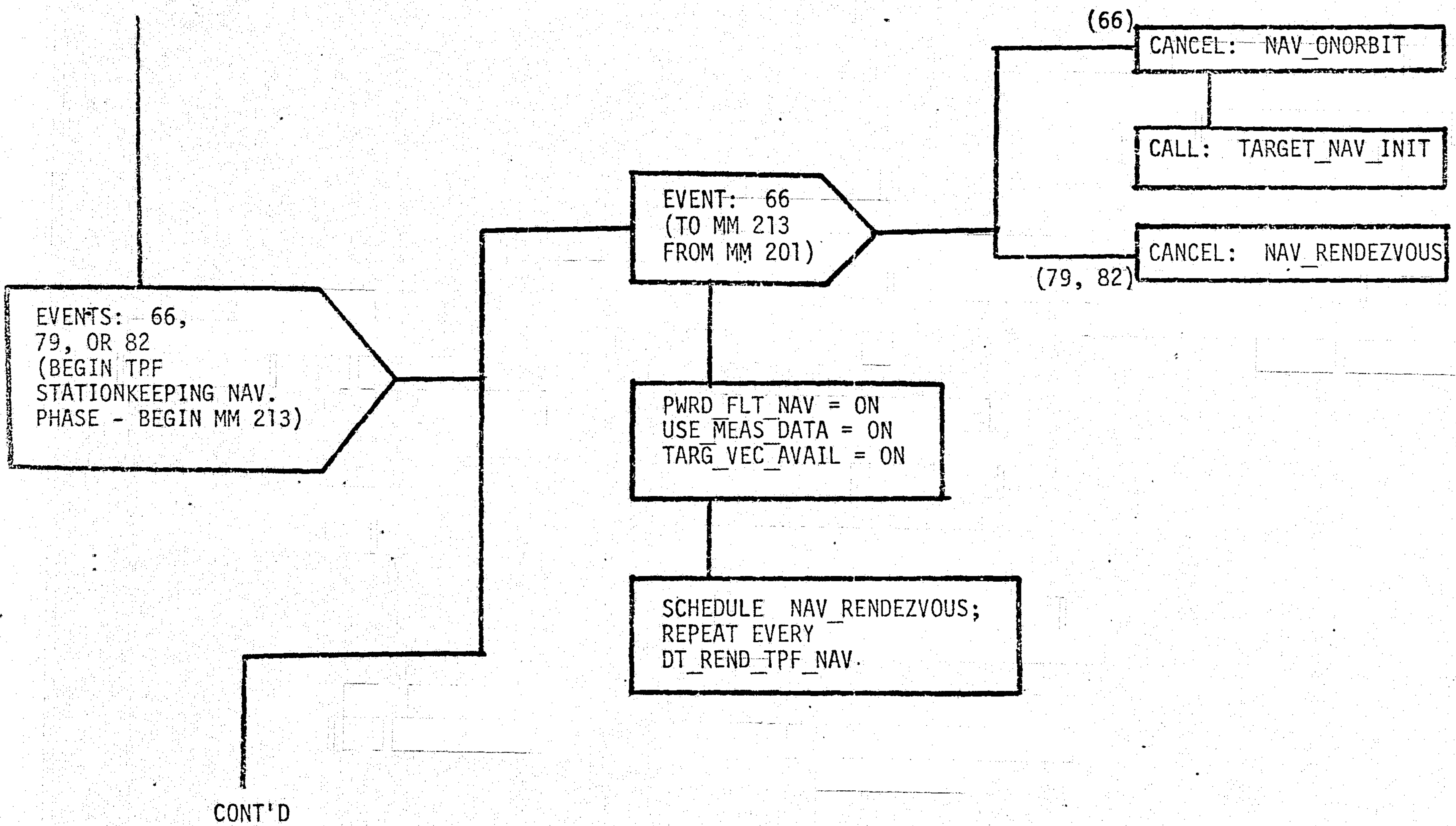
ONORBIT_REND_NAV_SEQUENCER (CONT'D)



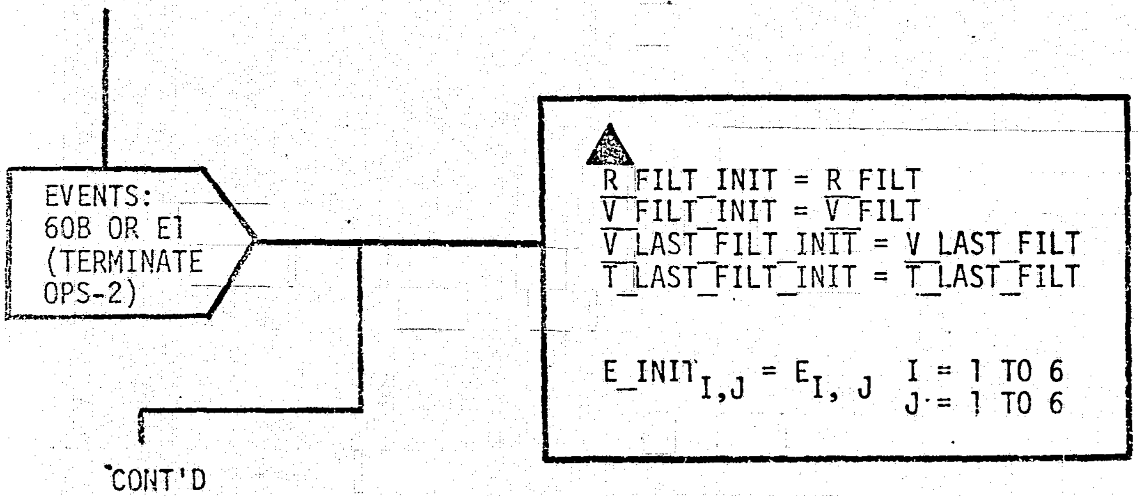
ONORBIT_REND_NAV_SEQUENCER (CONTINUED)



ONORBIT_REND_NAV_SEQUENCER (CONTINUED)



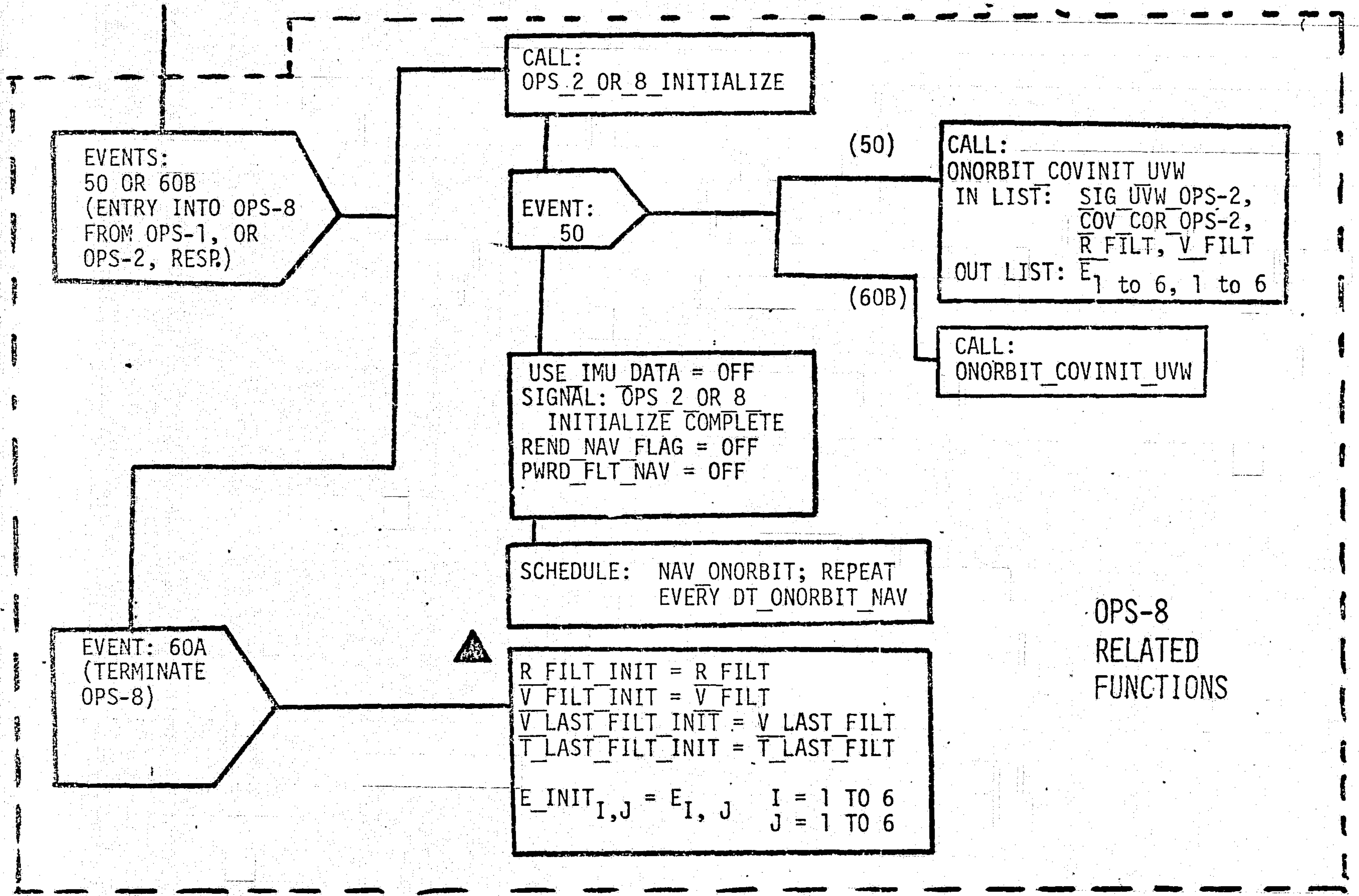
ONORBIT_REND_NAV_SEQUENCER (CONTINUED)



NOTES: 1. SAVED PARAMETERS IN PROTECTED MEMORY LOCATIONS FOR USE BY OPS-8 OR OPS-3 NAVIGATION SEQUENCER PRINCIPAL FUNCTIONS.

2. IT IS ASSUMED THAT APPROPRIATE CHECKPOINT DATA SETS HAVE BEEN STORED (VIA THE CHECKPOINT SPECIALIST FUNCTION) PERIODICALLY, AT A TBD RATE. A DATA SET SHALL ALSO BE STORED AS SOON AS POSSIBLE AFTER EACH BURN, AND AS SOON AS POSSIBLE AFTER EACH GROUND UPDATE.

ONORBIT_REND_NAV_SEQUENCER (CONCLUDED)



SAVED PARAMETERS IN PROTECTED MEMORY LOCATIONS FOR USE BY OPS-2 NAVIGATION SEQUENCER INITIALIZATION FUNCTIONS

CHECKPOINT_INIT (CODE)

SNAP IMU (V_LAST_FILT_INIT, T_LAST_FILT_INIT)

CALL: ONORBIT_PREDICT
INLIST: GM_DEG, GM_ORD, 1, 1, 1, PREC_STEP, R_CHECK_PT, V_CHECK_PT,
T_CHECK_PT, T_LAST_FILT_INIT
OUTLIST: R_FILT_INIT, V_FILT_INIT

OPS_2_OR_8_INITIALIZE

R_FILT = R_FILT_INIT, V_FILT = V_FILT_INIT
V_LAST_FILT = V_LAST_FILT_INIT

T_LAST_FILT = T_LAST_FILT_INIT
R_RESET = R_FILT_INIT, V_RESET = V_FILT_INIT
V_IMU_RESET = V_LAST_FILT_INIT, T_RESET = T_LAST_FILT_INIT
FILT_UPDATE = ON, B = 0.

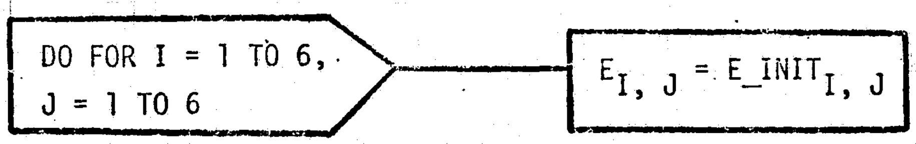
VENT_THRUST_BIAS = 0.
SQR_EMU = SQRT (EARTH_MU)
C_MX_AN = COS (MAX_DENS_ANGLE)
S_MX_AN = SIN (MAX_DENS_ANGLE)
C_MN_AN = COS (MIN_DENS_ANGLE)
S_MN_AN = SIN (MIN_DENS_ANGLE)

$E_{1\ TO\ 19,\ 1\ TO\ 19} = 0.$

DO FOR I = 7 TO 9 → $E_{I,\ I}$ = $COV\_ACCEL\_BODY\_INIT_{I-6}$

TOT_ACC = ACCEL_PERT_ONORBIT(GM_DEG, GM_ORD,
1,1,0, R_FILT, V_FILT, T_LAST_FILT)
-EARTH_MU R_FILT/|R_FILT|^3

ONORBIT_COVINIT



ONORBIT_COVINIT_UVW

IN LIST: SIG, COR, R, V

OUT LIST: E_TEMP

E_TEMP = 0.

DO FOR I = 1 TO 6

$E\_TEMP_{I,\ I} = SIG_I \quad SIG_I$

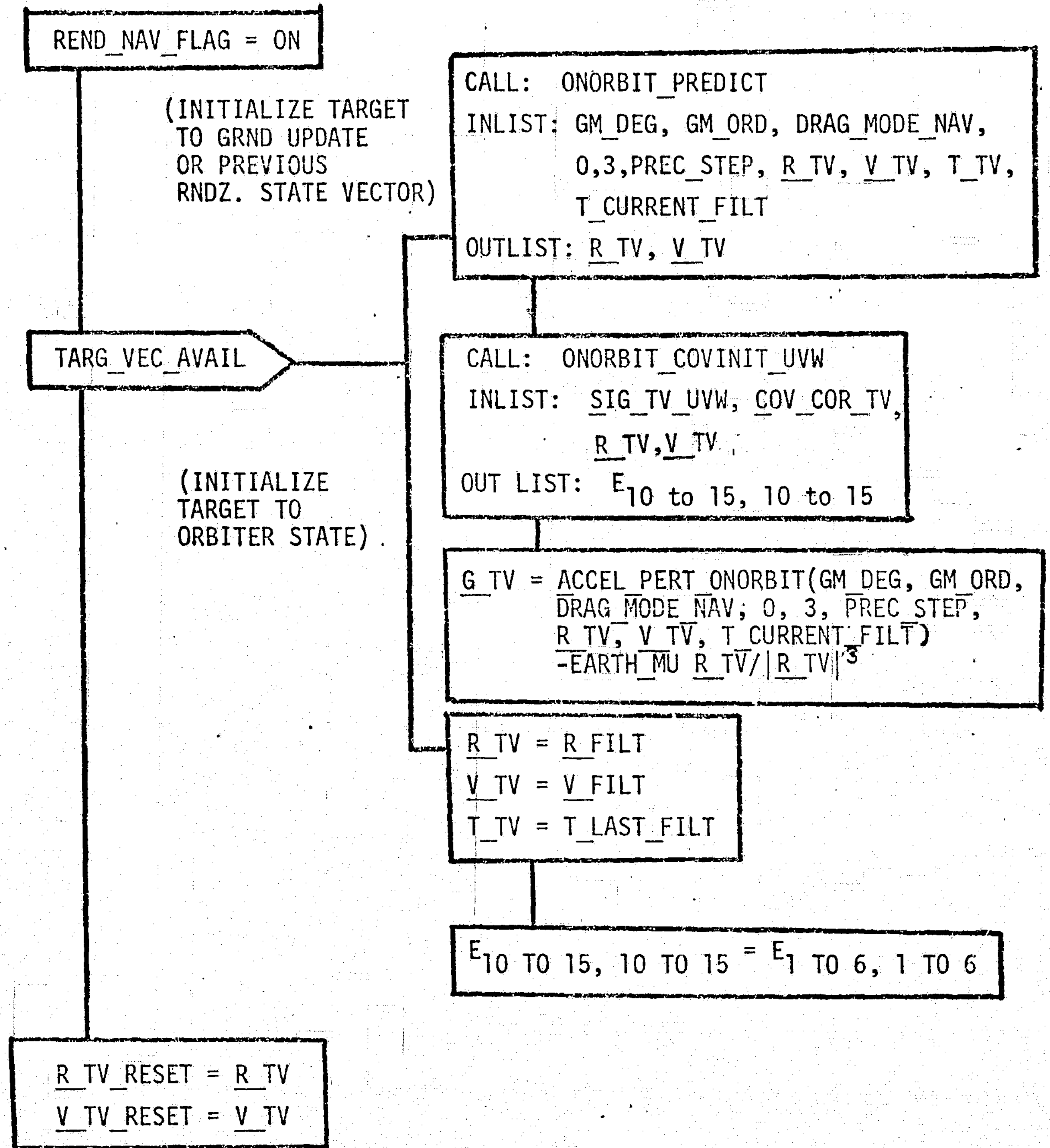
$E\_TEMP_{1,2} = COR_1\ SIG_1\ SIG_2$
$E\_TEMP_{1,4} = COR_2\ SIG_1\ SIG_4$
$E\_TEMP_{1,5} = COR_3\ SIG_1\ SIG_5$
$E\_TEMP_{2,4} = COR_4\ SIG_2\ SIG_4$
$E\_TEMP_{2,5} = COR_5\ SIG_2\ SIG_5$
$E\_TEMP_{3,6} = COR_6\ SIG_3\ SIG_6$
$E\_TEMP_{4,5} = COR_7\ SIG_4\ SIG_5$
$E\_TEMP_{2,1} = E\_TEMP_{1,2}$
$E\_TEMP_{5,4} = E\_TEMP_{4,5}$

M = UVW_TO_M50 (R,V)
$E\_TEMP_{1\ TO\ 3,\ 1\ TO\ 3} = M\ E\_TEMP_{1\ TO\ 3,\ 1\ TO\ 3}\ M^T$
$E\_TEMP_{4\ TO\ 6,\ 4\ TO\ 6} = M\ E\_TEMP_{4\ TO\ 6,\ 4\ TO\ 6}\ M^T$
$E\_TEMP_{1\ TO\ 3,\ 4\ TO\ 6} = M\ E\_TEMP_{1\ TO\ 3,\ 4\ TO\ 6}\ M^T$
$E\_TEMP_{4\ to\ 6,\ 1\ to\ 3} = (E\_TEMP_{1\ to\ 3,\ 4\ to\ 6})^T$

DISPLAY_COUNT_INIT (CODE)

```
N_ACCEPT = 0
N_REJECT = 0
SEQ_ACCEPT = 0
SEQ_REJECT = 0
```

TARGET_NAV_INIT



NAV_ONORBIT

SNAP IMU(V_CURRENT_FILT, T_CURRENT_FILT)

CALL:
ONORBIT_REND_R_V_STATE_PROP

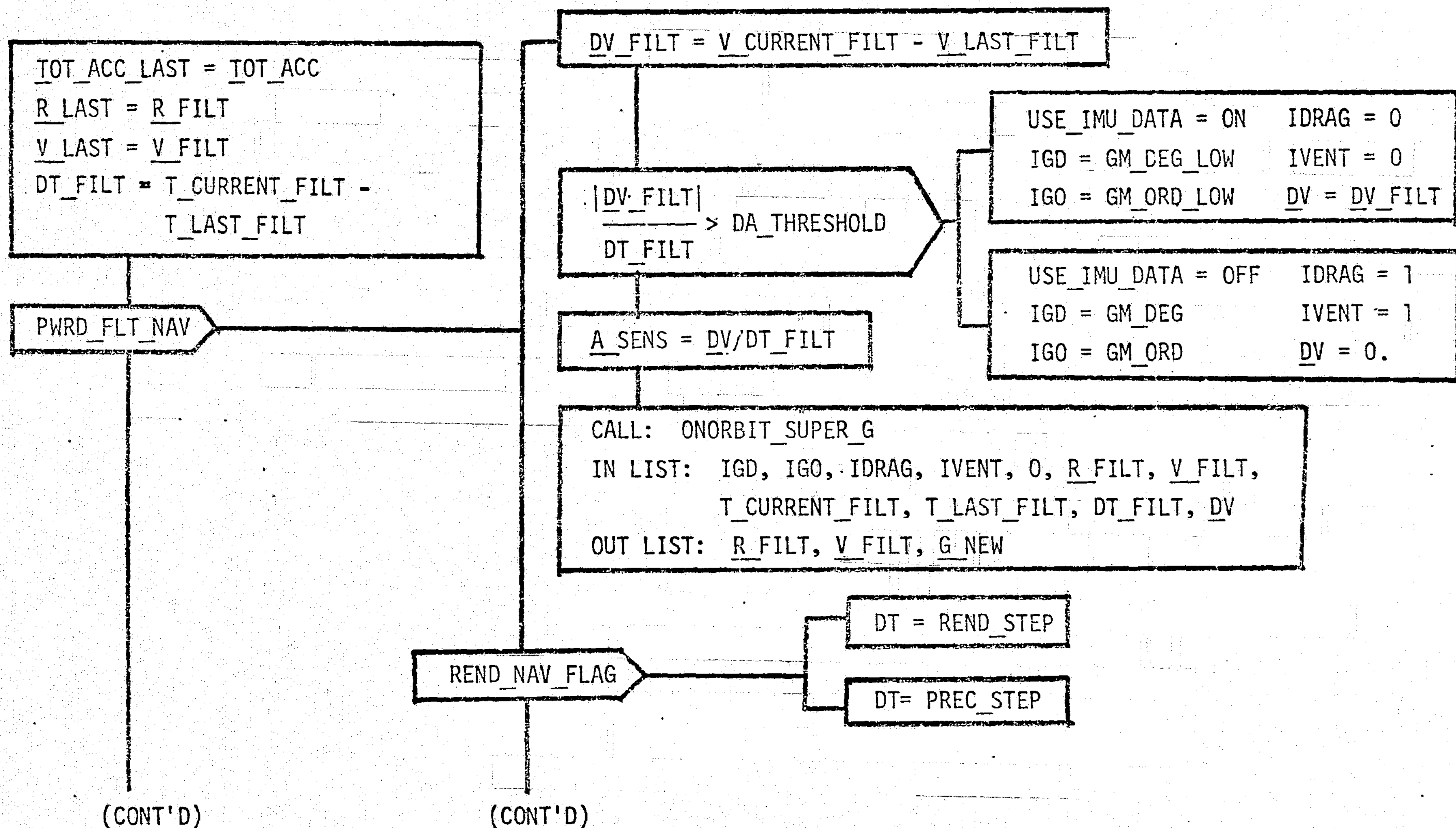
CALL:
ONORBIT_REND_BIAS_AND_COV_PROP

CALL:
ONORBIT_REND_AUTO_INFLIGHT_UPDATE

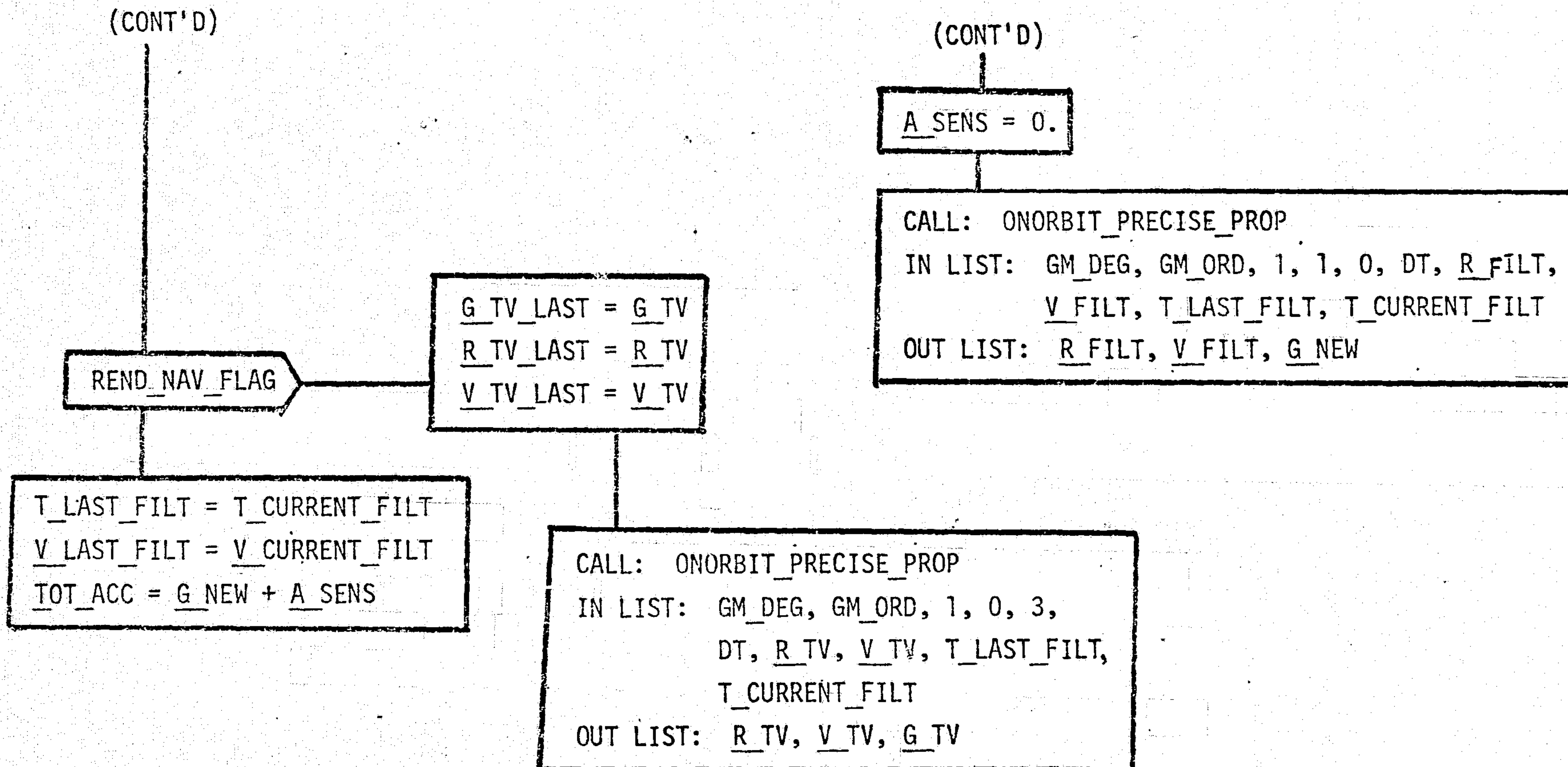
R_RESET = R_FILT
V_RESET = V_FILT
T_RESET = T_LAST_FILT
V_IMU_RESET = V_LAST_FILT

FILT_UPDATE = ON

ONORBIT_REND_R_V_STATE_PROP



ONORBIT_REND_R_V_STATE_PROP (CONCLUDED)



ONORBIT_SUPER_G

IN LIST: GD, GO, DFL, VFL, ATFL, R_SUP, V_SUP, T_CUR, DT, DV

OUT LIST: R_SUP, V_SUP, GR_NEW

R_SUP = R_SUP + DT [V_SUP + .5 (DV + DT GR_NEW)]

GR_INT = ACCEL_PERT_ONORBIT (GD, GO, DFL, VFL, ATFL, R_SUP, V_SUP, T_CUR)

GR_INT = GR_INT-EARTH_MU R_SUP/|R_SUP|^3

V_SUP = V_SUP + DV+ .5 DT (GR_INT + GR_NEW)

R_SUP = R_SUP + (GR_INT-GR_NEW) DT^2/6.

GR_NEW = ACCEL_PERT_ONORBIT (GD, GO, DFL, VFL, ATFL, R_SUP, V_SUP, T_CUR)

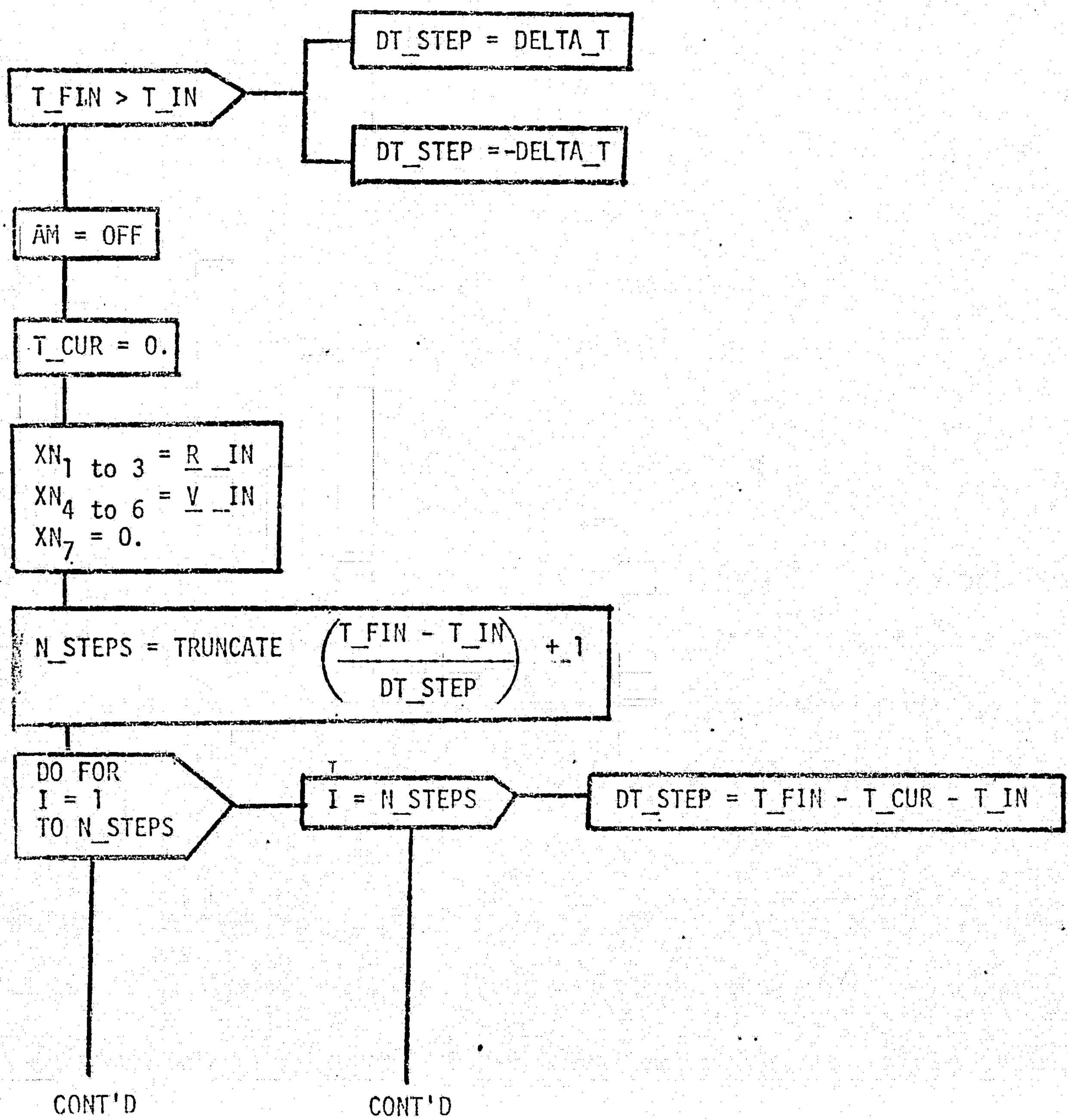
GR_NEW = GR_NEW-EARTH_MU R_SUP/|R_SUP|^3

B-10

ONORBIT_PRECISE_PROP

IN LIST: GMD, GMO, DM, VM, ATM, DELTA_T, R _ IN, V _IN, T_IN, T_FIN

OUT LIST: R _FIN, V _FIN, G _NEW



ONORBIT_PRECISE_PROP (CONCLUDED)

CALL: RK_GILL
IN LIST: XN, DT_STEP, I, T_CUR, AM, GMO, GMD, DM, VM, ATM, T_IN
OUT LIST: XN, T_CUR

CALL: PINES_METHOD
IN LIST: XN, T_CUR, GMO, GMD, DM, VM, ATM, T_IN
OUT LIST: DERIV, X

$\underline{R}$_FIN = $X_{1 \text{ to } 3}$

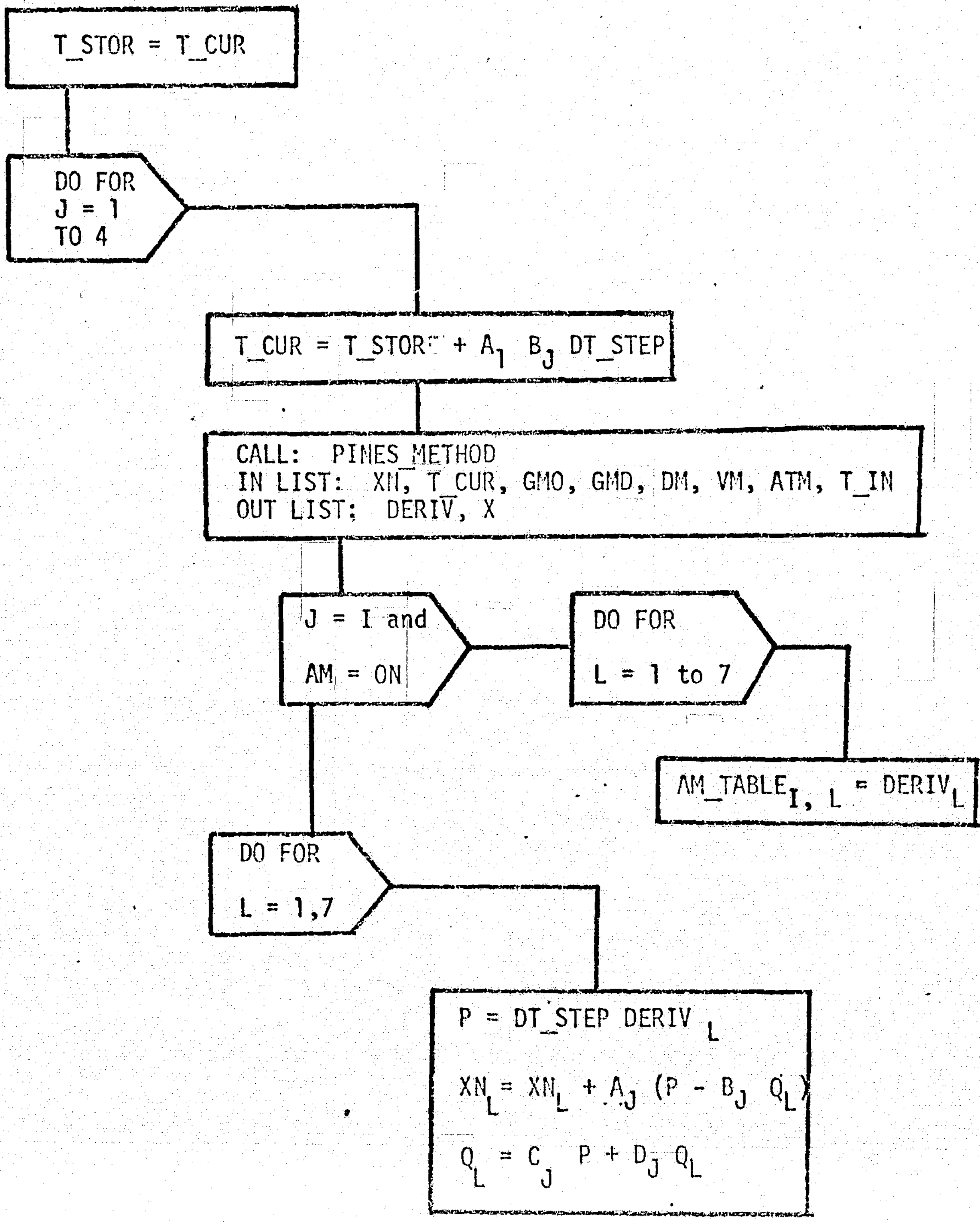
$\underline{V}$_FIN = $X_{4 \text{ to } 6}$

$\underline{G}$_NEW = ACCEL_PERT_ONORBIT (GMD, GMO, DM, VM, ATM, $\underline{R}$_FIN, $\underline{V}$_FIN, T_FIN)-EARTH_MU $\underline{R}$_FIN/|$\underline{R}$_FIN|^3

RK_GILL

IN LIST: XN, DT_STEP, I, T_CUR, AM, GMO, GMD, DM, VM, ATM, T_IN

OUT LIST: XN, T_CUR



PINES_METHOD

IN LIST: XN, T_CUR, GMO, GMD, DM, VM, ATM, T_IN

OUT LIST: DERIV, X

R_IN = $|XN_{1\ to\ 3}|$

R_IN_INV = 1./R_IN

SMA = 1./[2.R_IN_INV - ($XN_{4\ to\ 6} \cdot XN_{4\ to\ 6}$)/EARTH_MU]

C1 = SQRT(SMA)/SQR_EMU

DELTAT = T_CUR-XN_7

D_IN = $XN_{1\ to\ 3} \cdot XN_{4\ to\ 6}$

CALL: F_AND_G

IN LIST: SMA, DELTAT, C1, $XN_{1\ to\ 3}$, 0., 0., 0., R_IN_INV, 0., $XN_{4\ to\ 6}$, D_IN,0.

OUT LIST: F, G, FDOT, GDOT, S0, S1, S2, S3, $X_{1\ to\ 3}$, R_FIN_INV, THETA

$X_{4\ to\ 6}$ = FDOT $XN_{1\ to\ 3}$ + GDOT $XN_{4\ to\ 6}$

T_ACCEL = T_IN + T_CUR

$\underline{P}$ = ACCEL_PERT_ONORBIT (GMD, GMO, DM, VM, ATM, $X_{1\ to\ 3}$, $X_{4\ to\ 6}$, T_ACCEL)

D_TAU = $X_{1\ to\ 3} \cdot \underline{P}$

D_AUX = $X_{4\ to\ 6} \cdot \underline{P}$

cont'd

PINES_METHOD (CONCLUDED)

C2 = $C1^2$	C3 = 1./C2	C4 = C2 D_AUX
S1 = C1 S1	S3 = SMA S2	C5 = C4 S1
S2 = C2 S2	S4 = 2.S3 D_AUX	S5 = S2 D_TAU

DD = S1 C3 R_IN(SMA R_IN_INV-1.) +SO D_IN

S6 = 2. S2 C4 DD + S5

R_IN_TAU = S4-C2 S1 D_AUX-S1 D_TAU

R_IN_AUX = R_IN_INV R_IN_TAU

F_TAU = S3 C3 R_IN_INV R_IN_AUX - S4

G_TAU = C5 R_IN - S6

FD_TAU = FDOT (C4-R_IN_AUX)

GD_TAU = S4 R_FIN_INV

$DERIV_{i1\ to\ 3} = GD\_TAU\ X_{1\ to\ 3} - G\_TAU\ X_{4\ to\ 6} - G\ \underline{P}$

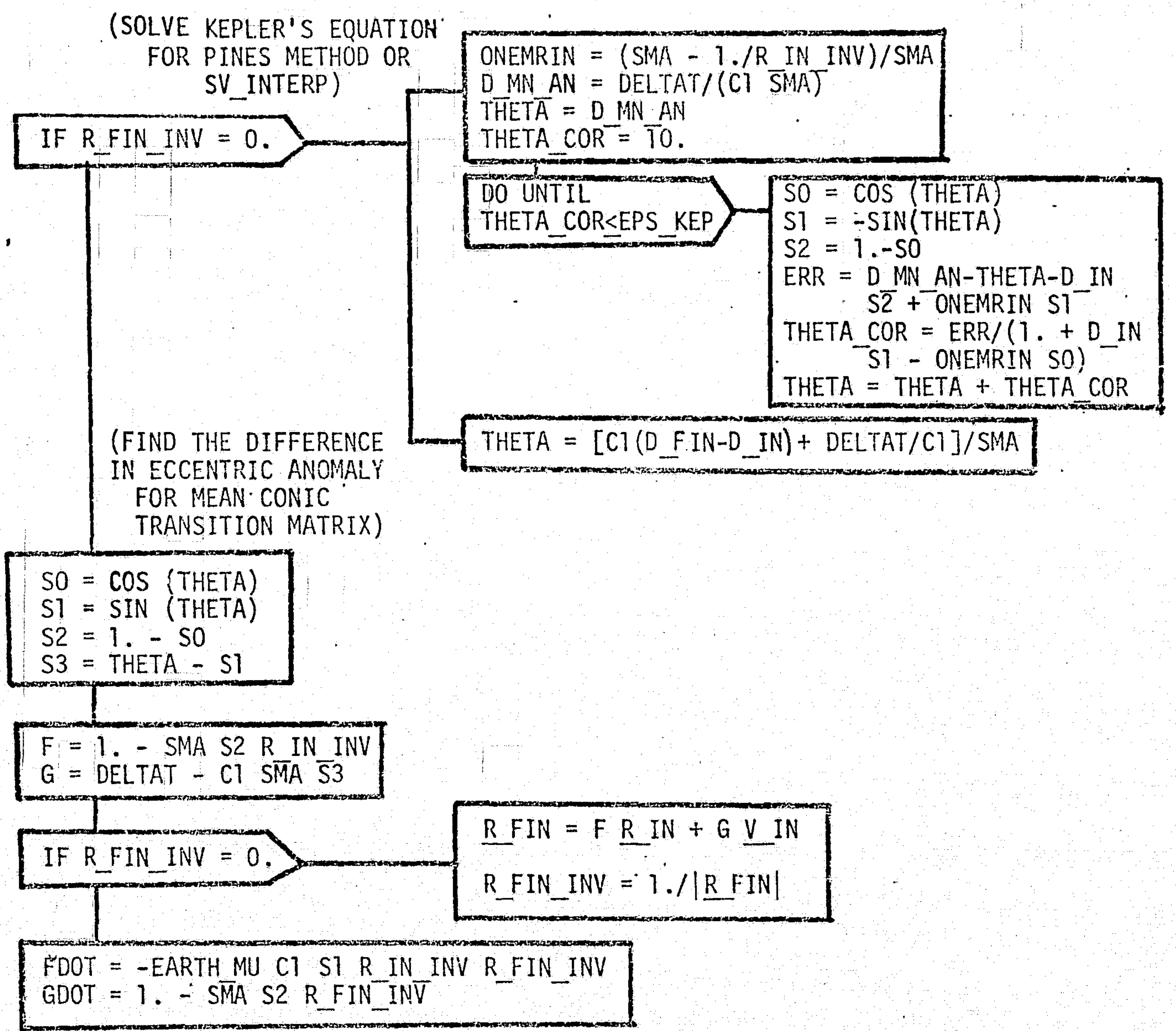
$DERIV_{4\ to\ 6} = -FD\_TAU\ X_{1\ to\ 3} + F\_TAU\ X_{4\ to\ 6} + F\ \underline{P}$

$DERIV_{7} = S6 - 3.\ C1\ C4\ SMA\ THETA - C5/R\_FIN\_INV$

F_AND_G

IN LIST: SMA, DELTAT, C1, R_IN, R_FIN, R_IN_INV, R_FIN_INV, V_IN, D_IN, D_FIN

OUT LIST: F, G, FDOT, GDOT, S0, S1, S2, S3, R_FIN, R_FIN_INV, THETA



ONORBIT_REND_BIAS_AND_COV_PROP

CALL: MEAN_CONIC_PARTIAL_TRANSITION_MATRIX_6X6

IN LIST: $\underline{R}$_LAST, $\underline{V}$_LAST, $\underline{T}$OT_ACC_LAST, $\underline{R}$_FILT, $\underline{V}$_FILT, $\underline{T}$OT_ACC, DT_FILT

OUT LIST $PHI_{1 \text{ to } 6,\ 1 \text{ to } 6}$

PWRD_FLT_NAV = ON → EXECUTE: PWRD_FILT_COV_PROP (CODE)

DO FOR I = 1 to 3

$PHI_{I+6,\ I+6} = e^{-DT\_FILT/TAU\_VENT_I}$

$DIAG_I = TAU\_VENT_I\ (1. - PHI_{I+6,\ I+6})$

$S_{I+6,\ I+6} = TAU\_VENT_I\ VAR\_VENT\ DT_I \left(1. - PHI^2_{I+6,\ I+6}\right)$

DO FOR J = 1 to 3

$PHI_{J+3,\ I+6} = M\_SBODYM50_{J,I} DIAG_I$

$PHI_{J,\ I+6} = M\_SBODYM50_{J,I}\ (TAU\_VENT_I\ (DT\_FILT - DIAG_I))$

$\underline{DIAG} = DT\_FILT\ \underline{D}\_COE\_PCT\_ERR\ \underline{D}$

$S_{4 \text{ to } 6,\ 4 \text{ to } 6} = \underline{DIAG}\ \underline{DIAG}^T$

$S_{4 \text{ to } 6,\ 1 \text{ to } 3} = .5\ DT\_FILT\ S_{4 \text{ to } 6,\ 4 \text{ to } 6}$

$S_{1 \text{ to } 3,\ 4 \text{ to } 6} = S_{4 \text{ to } 6,\ 1 \text{ to } 3}$

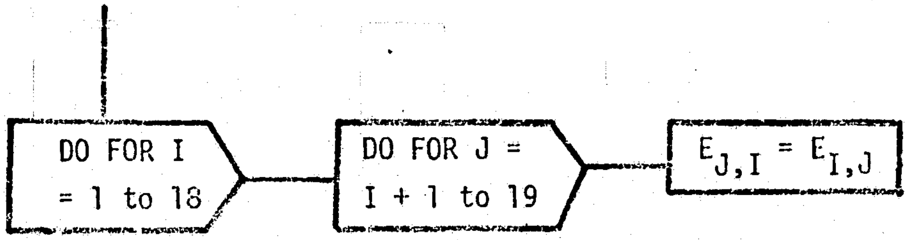
$S_{1 \text{ to } 3,\ 1 \text{ to } 3} = .5\ DT\_FILT\ S_{4 \text{ to } 6,\ 1 \text{ to } 3}$

$E_{1 \text{ to } 9,\ 1 \text{ to } 9} = PHI\ E_{1 \text{ to } 9,\ 1 \text{ to } 9}\ PHI^T + S$

REND_NAV_FLAG = ON → EXECUTE: REND_COV_PROP (CODE)

(CONT'D)

ONORBIT_REND_BIAS_AND_COV_PROP (CONCLUDED)



PWRD_FLT_COV_PROP (CODE)

DO FOR I = 1 to 3

$DIAG_I = VAR\_IMU\_ALIGN_I + (T\_LAST\_FILT - T\_ALIGN)^2 \ VAR\_IMU\_DRIFT_I$

$S_{4,4} = DV\_FILT_3^2 \ DIAG_2 + DV\_FILT_2^2 \ DIAG_3$

$S_{5,5} = DV\_FILT_1^2 \ DIAG_3 + DV\_FILT_3^2 \ DIAG_1$

$S_{6,6} = DV\_FILT_1^2 \ DIAG_2 + DV\_FILT_2^2 \ DIAG_1$

$S_{4,5} = -DV\_FILT_1 \ DV\_FILT_2 \ DIAG_3$

$S_{4,6} = -DT\_FILT_1 \ DV\_FILT_3 \ DIAG_2$

$S_{5,6} = -DV\_FILT_2 \ DV\_FILT_3 \ DIAG_1$

$S_{5,4} = S_{4,5}, \ S_{6,4} = S_{4,6}, \ S_{6,5} = S_{5,6}$

$S_{1 \text{ to } 3,\ 4 \text{ to } 6} = .5 \ DT\_FILT \ S_{4 \text{ to } 6,\ 4 \text{ to } 6}$

$S_{4 \text{ to } 6,\ 1 \text{ to } 3} = S_{1 \text{ to } 3,\ 4 \text{ to } 6}$

$S_{1 \text{ to } 3,\ 1 \text{ to } 3} = .5 \ DT\_FILT \ S_{1 \text{ to } 3,\ 4 \text{ to } 6}$

$NOISE = VAR\_ACC\_QUANT + (VAR\_UNMOD\_ACC\_DT) \ DT\_FILT$

$NOISE\_R = .25 \ NOISE \ (DT\_FILT)^2$

$NOISE\_RV = .5 \ NOISE \ (DT\_FILT)$

DO FOR I = 1 to 3

$S_{I,I} = S_{I,I} + NOISE\_R$

$S_{I+3,\ I+3} = S_{I+3,\ I+3} + NOISE$

$S_{I+3,\ I} = S_{I+3,\ I} + NOISE\_RV$

$S_{I,\ I+3} = S_{I+3,\ I}$

$$E_{1 \text{ to } 6,\ 1 \text{ to } 6} = PHI_{1 \text{ to } 6,\ 1 \text{ to } 6} \ E_{1 \text{ to } 6,\ 1 \text{ to } 6} \ PHI^T_{1 \text{ to } 6,\ 1 \text{ to } 6} + S_{1 \text{ to } 6,\ 1 \text{ to } 6}$$

REND_COV_PROP (CODE)

CALL: MEAN_CONIC_PARTIAL_TRANSITION_MATRIX_6X6
IN LIST: R_TV_LAST, V_TV_LAST, G_TV_LAST, R_TV, V_TV, G_TV, DT_FILT
OUT LIST: $\text{PHI\_REND}_{1 \text{ to } 6,\ 1 \text{ to } 6}$

DO FOR I = 1 to 4

$$\text{PHI\_REND}_{I+6,\ I+6} = e^{-\text{DT\_FILT}/\text{TAU\_SENS}_I}$$

$$\text{S\_REND}_{I+6,\ I+6} = \text{TAU\_SENS}_I\ \text{VAR\_SENS\_DT}_I\ (1. - \text{PHI\_REND}^2_{I+6,\ I+6})$$

$$E_{10 \text{ to } 19,\ 10 \text{ to } 19} = \text{PHI\_REND}\ E_{10 \text{ to } 19,\ 10 \text{ to } 19}\ \text{PHI\_REND}^T + \text{S\_REND}$$

$$E_{1 \text{ to } 9,\ 10 \text{ to } 19} = \text{PHI}\ E_{1 \text{ to } 9,\ 10 \text{ to } 19}\ \text{PHI\_REND}^T$$

B-17

MEAN_CONIC_PARTIAL_TRANSITION_MATRIX_6X6

IN LIST: R_ONE, V_ONE, G_ONE, R_ONE, R_TWO, V_TWO, G_TWO, DELTIM
OUT LIST: PHI_MC

R_ONE_INV = 1./|R_ONE| D_ONE = R_ONE · V_ONE
R_TWO_INV = 1./|R_TWO| D_TWO = R_TWO · V_TWO

SMA = 1./[R_ONE_INV + R_TWO_INV - (V_ONE·V_ONE + V_TWO·V_TWO)/2. EARTH_MU]
C1 = SQRT(SMA)/SQR_EMU

CALL: F_AND_G
IN LIST: SMA, DELTIM, C1, R_ONE, R_TWO, R_ONE_INV, R+TWO_INV, V_ONE, D_ONE, D_TWO
OUT LIST: F, G, FDOT, GDOT, S0, S1, S2, S3, R_TWO, R_TWO_INV, THETA

FM1 = F-1.   S1 = C1 S1   CONST = C1 C2 SMA THETA (2. + S0) -3.C2 SMA S1
GDM1 = GDOT-1   C2 = $C1^2$ S2 = C2 S2

A1 = (FDOT S1 + FM1 R_ONE_INV) R_ONE_INV; A2 + FDOT S2; A3 = FM1 S1 R_ONE_INV; A4 = FM1 S2; A5 = GDM1 S2; A6 = G S2; A7 = FDOT (S0 R_ONE_INV R_TWO_INV + R_ONE_INV^2 + R_TWO_INV^2); A8 = (FDOT S1 + GDM1 R_TWO_INV) R_TWO_INV; A9 = GDM1 S1 R_TWO_INC

TEMP = A4 V_TWO-A2 R_TWO

PHI_MC$_{1 \text{ to } 3,\ 1 \text{ to } 3}$ = F ID_MATRIX_3X3 + CONST V_TWO G_ONE + (A3 V_TWO-A1 R_TWO) R_ONE + TEMP V_ONE

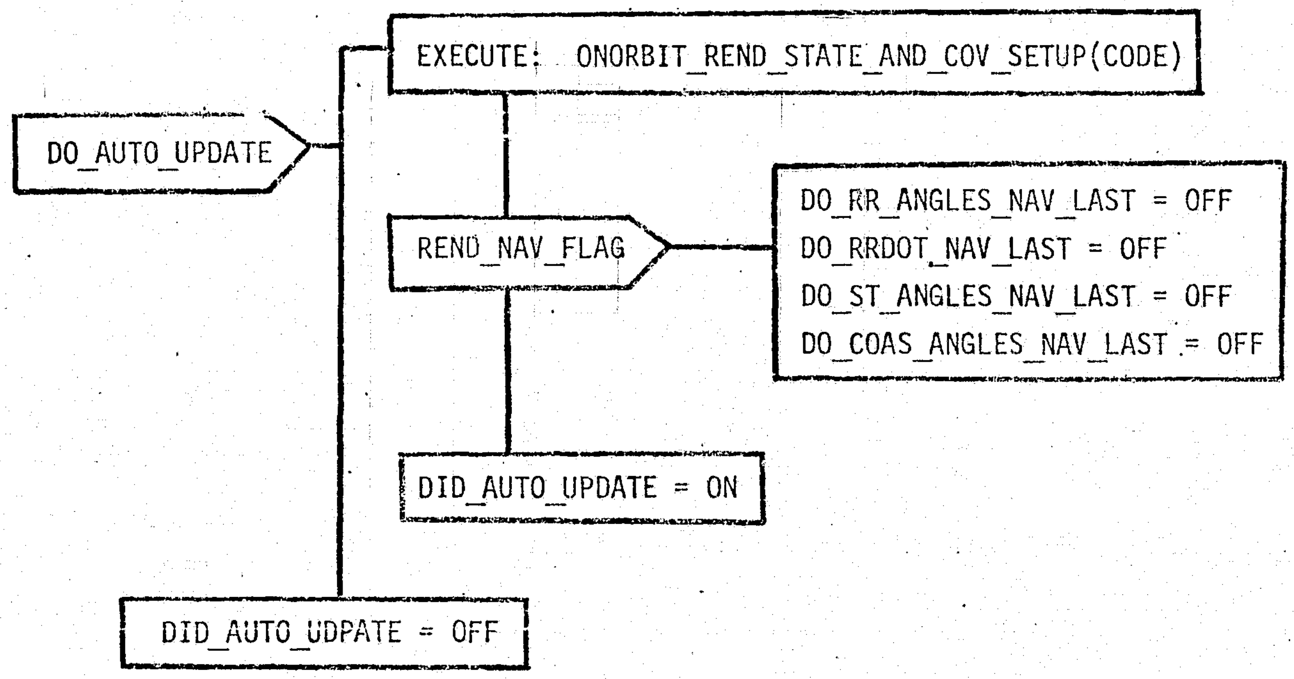
PHI_MC$_{1 \text{ to } 3,\ 4 \text{ to } 6}$ = G ID_MATRIX_3X3 - CONST V_TWO V_ONE + TEMP R_ONE + (A6 V_TWO - A5 R_TWO) V_ONE

TEMP = A2 V_TWO - A8 R_TWO

PHI_MC$_{4 \text{ to } 6,\ 1 \text{ to } 3}$ = FDOT ID_MATRIX_3X3 + CONST G_TWO G_ONE + (A1 V_TWO - A7 R_TWO) R_ONE + TEMP V_ONE

PHI_MC$_{4 \text{ to } 6,\ 4 \text{ to } 6}$ = GDOT ID_MATRIX_3X3 - CONST G_TWO V_ONE + TEMP R_ONE + (A5 V_TWO - A9 R_TWO) V_ONE

ONORBIT_REND_AUTO_INFLIGHT_UPDATE



ONORBIT_REND_STATE_AND_COV_SETUP (CODE)

OV_UPLINK →

$E_{1 \text{ TO } 9,\ 1 \text{ TO } 9} = 0.$

REND_NAV_FLAG →

$E_{1 \text{ TO } 9,\ 10 \text{ TO } 19} = 0.$

$E_{10 \text{ TO } 19,\ 1 \text{ TO } 9} = 0.$

CALL: ONORBIT_PREDICT

INLIST: GM_DEG, GM_ORD, DRAG_MODE_NAV,
VENT_MODE_NAV, 1, PREC_STEP, R_GND,
V_GND, T_GND, T_CURRENT_FILT

OUTLIST: R_FILT, V_FILT

CALL: ONORBIT_COVINIT_UVW

INLIST: SIG_UPDATE, COV_COR_UPDATE,
R_FILT, V_FILT

OUT LIST: $E_{1 \text{ to } 6,\ 1 \text{ to } 6}$

TOT_ACC = ACCEL_PERT_ONORBIT (GM_DEG, GM_ORD, 1, 1, 0,
R_FILT, V_FILT, T_CURRENT_FILT)
- EARTH_MU R_FILT/|R_FILT|^3

DO FOR
I = 1 TO 3 →

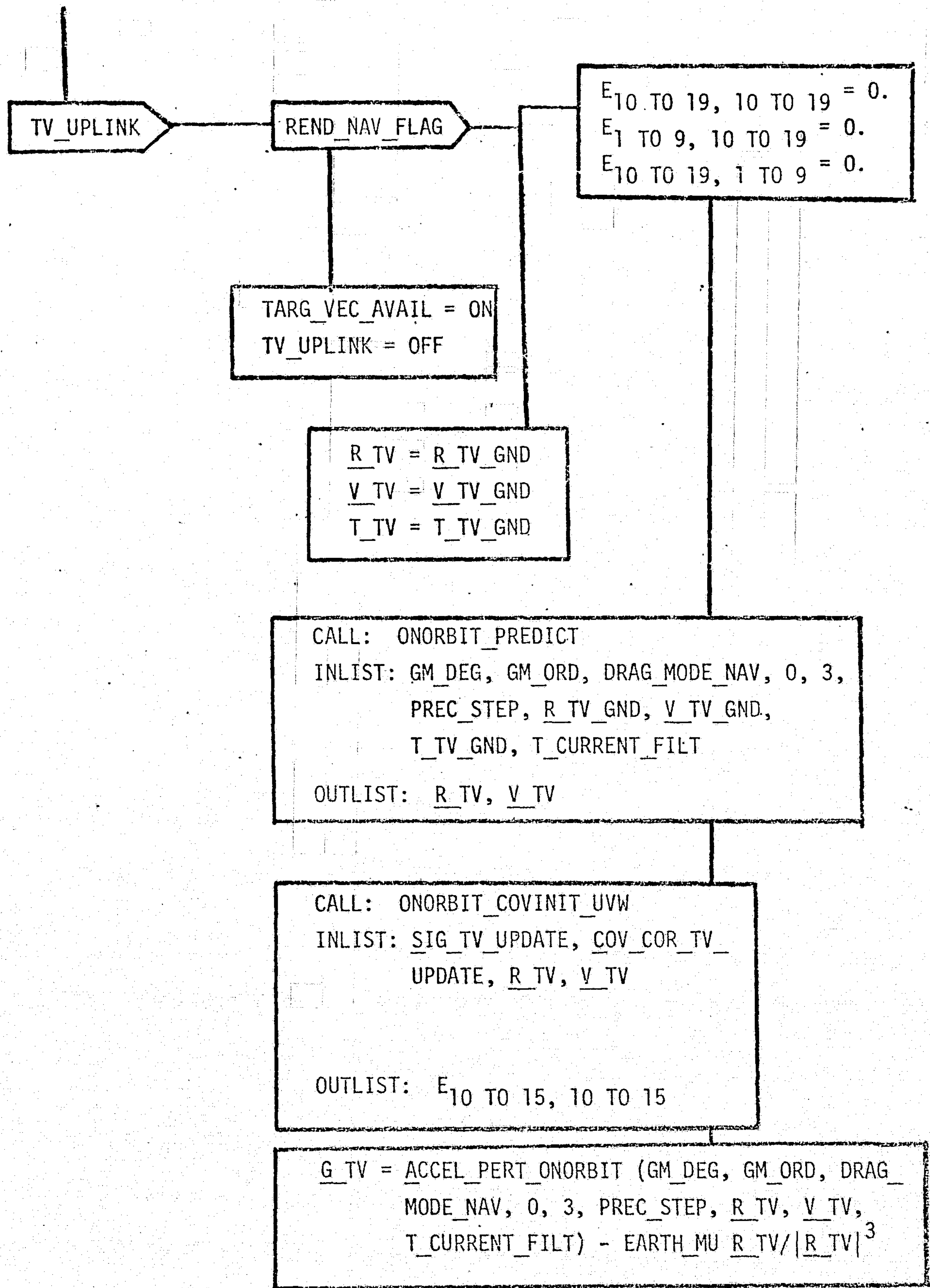
$E_{I+6,\ I+6}$ = COV_ACCEL_BODY_INIT$_I$

VENT_THRUST_BIAS$_I$ = 0.

OV_UPLINK = OFF

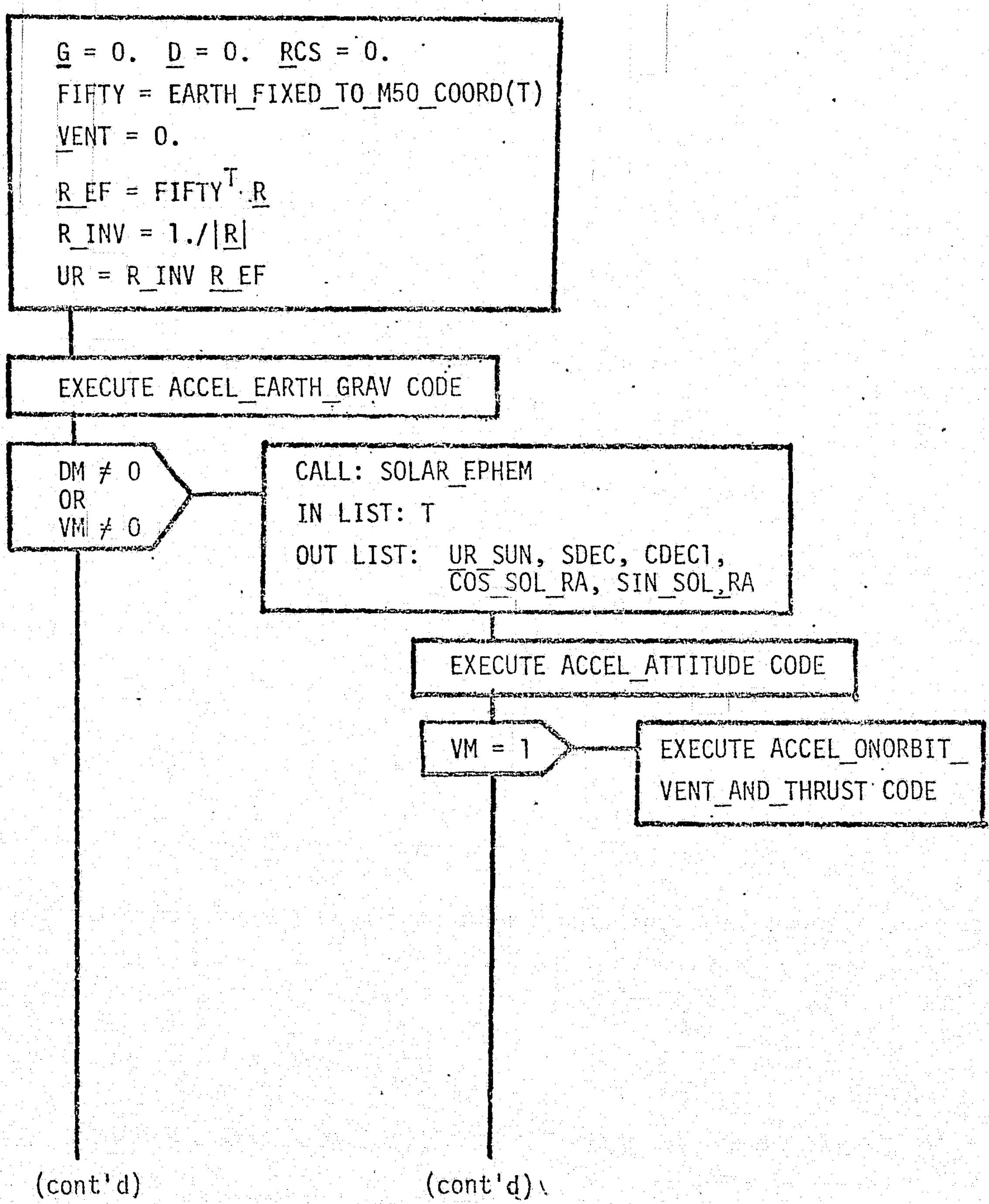
CONT'D

ONORBIT_REND_STATE_AND_COV_SETUP (CODE), CONCLUDED

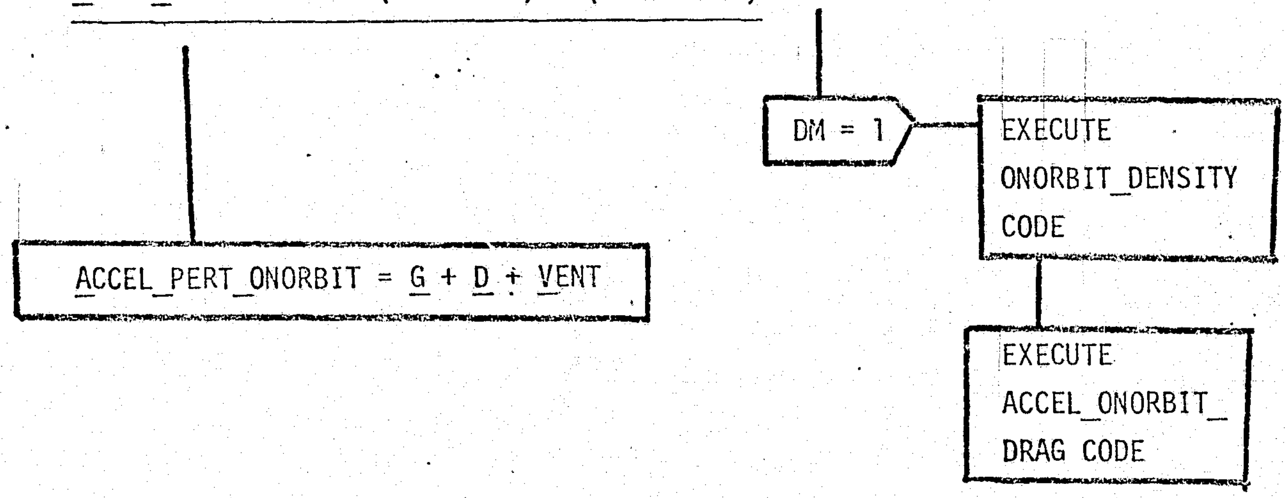


ACCEL_PERT_ONORBIT (FUNCTION)

IN LIST: GMD, GMO, DM, VM, ATM, R, V, T



ACCEL_PERT ONORBIT (FUNCTION) (CONCLUDED)



GMD controls the use of zonal harmonics in the gravity model.

GMO controls the use of tesseral harmonics in the gravity model.

DM controls the use or non-use of drag acceleration model.

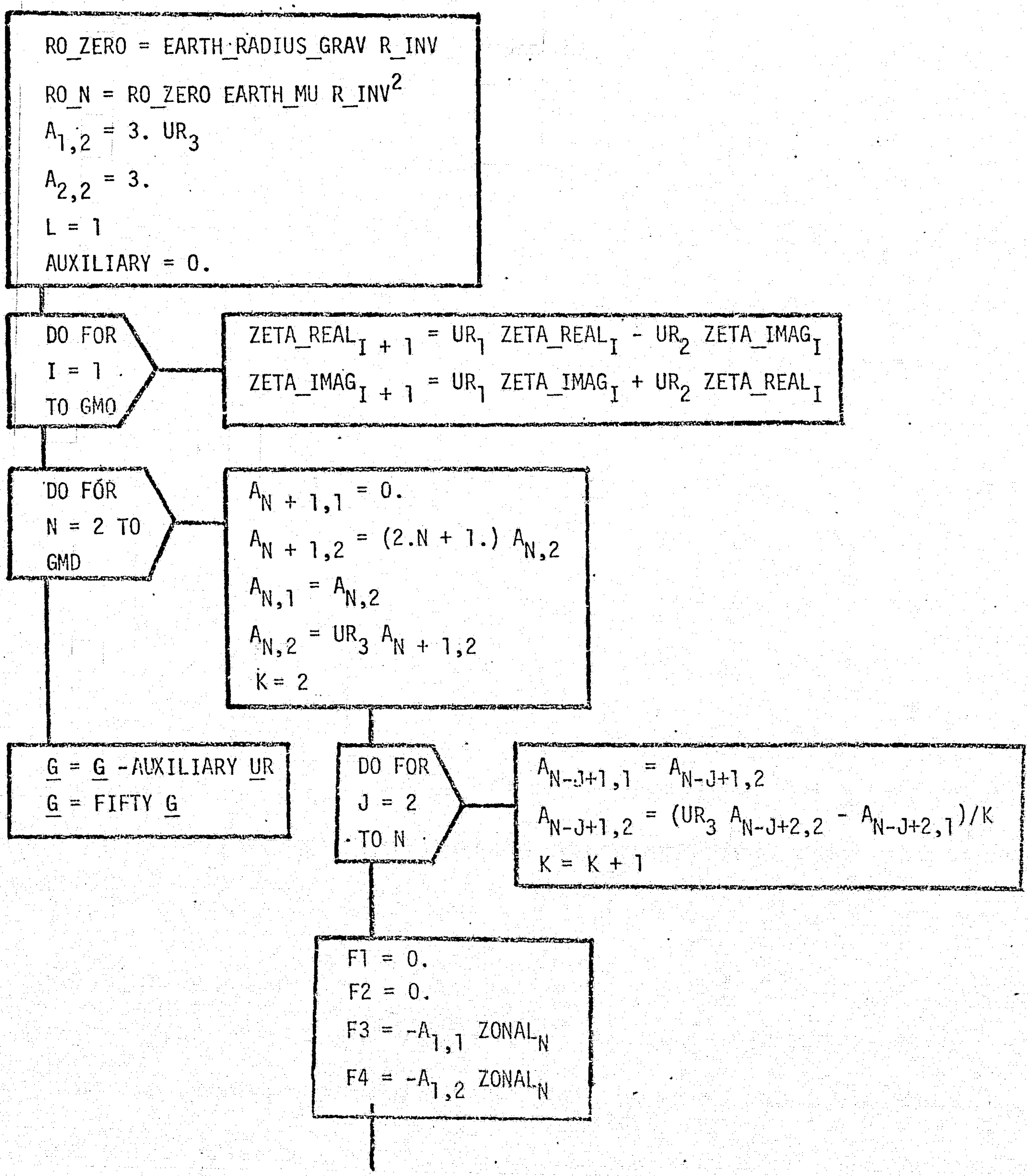
VM controls the use or non-use of venting and uncoupled thrusting model.

ATM controls the use or non-use of prestored attitude profile, average area, mass, and drag coefficient of orbiter on target vehicle.

R, V are the position and velocity vectors of the vehicle in M50 coordinates.

T is the time.

ACCEL_EARTH_GRAV CODE



(CONT'D)

ACCEL_EARTH_GRAV CODE (CONCLUDED)

$N \leq GMO$

DO FOR
$N1 = 1$
TO N

$F1 = F1 + N1\ A_{N1,1}(C_L\ ZETA\_REAL_{N1} + S_L\ ZETA\_IMAG_{N1})$

$F2 = F2 + N1\ A_{N1,1}(S_L\ ZETA\_REAL_{N1} - C_L\ ZETA\_IMAG_{N1})$

$DNM = C_L\ ZETA\_REAL_{N1+1} + S_L\ ZETA\_IMAG_{N1+1}$

$F3 = F3 + DNM\ A_{N1+1,1}$

$F4 = F4 + DNM\ A_{N1+1,2}$

$L = L + 1$

$RO\_N = RO\_N\ RO\_ZERO$

$G_1 = G_1 + RO\_N\ F1$

$G_2 = G_2 + RO\_N\ F_2$

$G_3 = G_3 + RO\_N\ F3$

$AUXILIARY = AUXILIARY + RO\_N\ F4$

SOLAR_EPHEM

IN LIST: T

OUT LIST: UR_SUN, SDEC, CDEC1, COS_SOL_RA, SIN_SOL_RA

T1 = T/3155760000.

SOL_AUXIL = SOL_PARAM_ZERO + T1 SOL_PARAM_FIRST

SOL_TRUE_ANOM = SOL_AUXIL$_4$ + 2. SOL_AUXIL$_3$ SIN(SOL_AUXIL$_4$)

SOL_LONG = SOL_AUXIL$_1$ + SOL_TRUE_ANOM

S_S_L = SIN(SOL_LONG)

SDEC = S_S_L SIN(SOL_AUXIL$_2$)

CDEC1 = SQRT(1. - SDEC^2)

FACTOR = 1./CDEC1

UR_SUN$_1$ = COS(SOL_LONG)

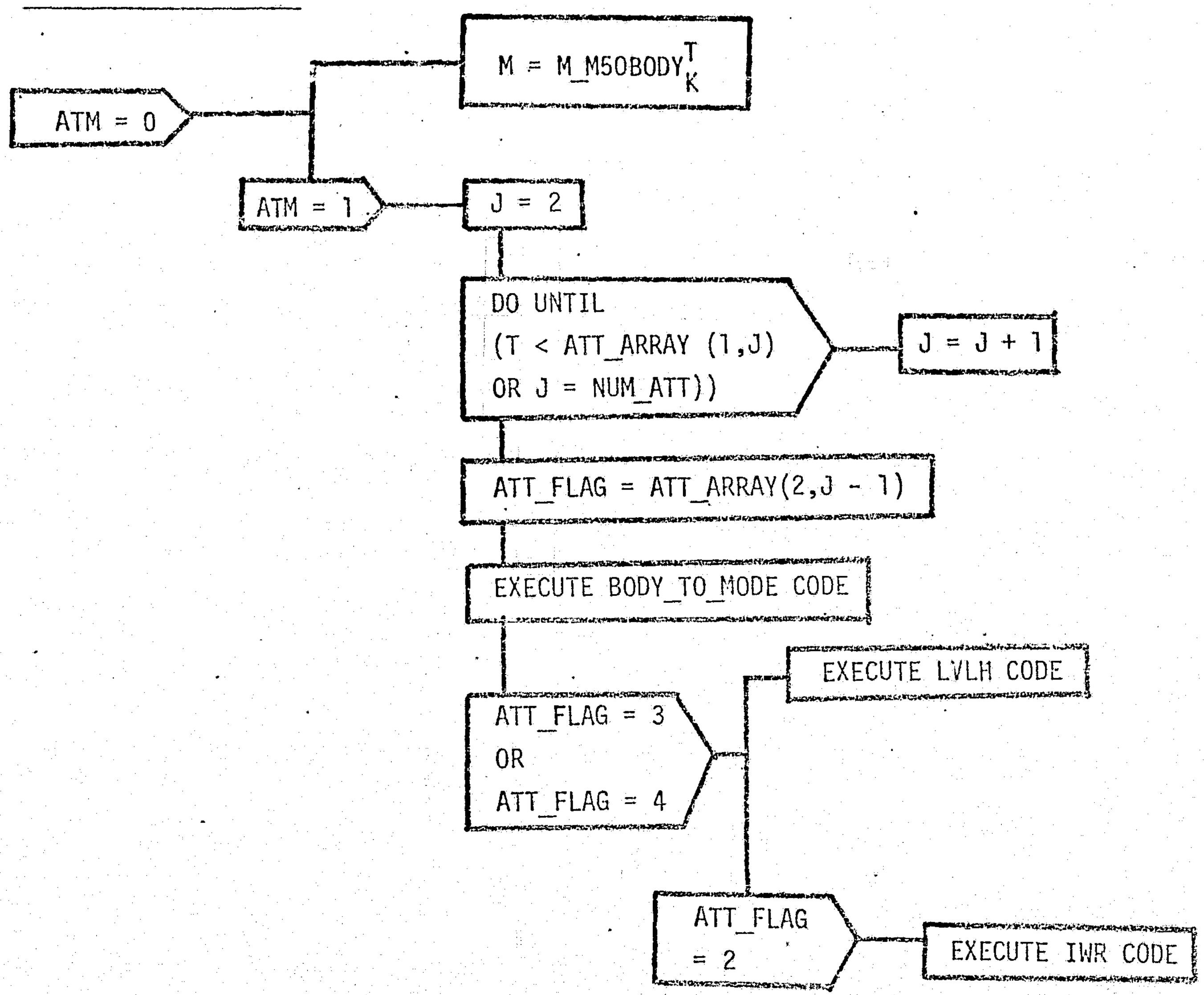
UR_SUN$_2$ = S_S_L COS(SOL_AUXIL$_2$)

UR_SUN$_3$ = SDEC

COS_SOL_RA = FACTOR UR_SUN$_1$

SIN_SOL_RA = FACTOR UR_SUN$_2$

ACCEL_ATTITUDE CODE



BODY_TO_MODE CODE

$S1 = SIN\ (ATT\_ARRAY_{3,J-1})$
$S2 = SIN\ (ATT\_ARRAY_{4,J-1})$
$S3 = SIN\ (ATT\_ARRAY_{5,J-1})$
$C1 = COS\ (ATT\_ARRAY_{3,J-1})$
$C2 = COS\ (ATT\_ARRAY_{4,J-1})$
$C3 = COS\ (ATT\_ARRAY_{5,J-1})$

$$M = \begin{bmatrix} C3\ C1 - S3\ C2\ S1 & C3\ S1 + S3\ C2\ C1 & S3\ S2 \\ -S3\ C1 - C3\ C2\ S1 & -S3\ S1 + C3\ C2\ C1 & C3\ S2 \\ S2\ S1 & -S2\ C1 & C2 \end{bmatrix}$$

LVLH CODE

```
M_TEMP = UVW_TO_M50(R, V)

M = M_TEMP M
```

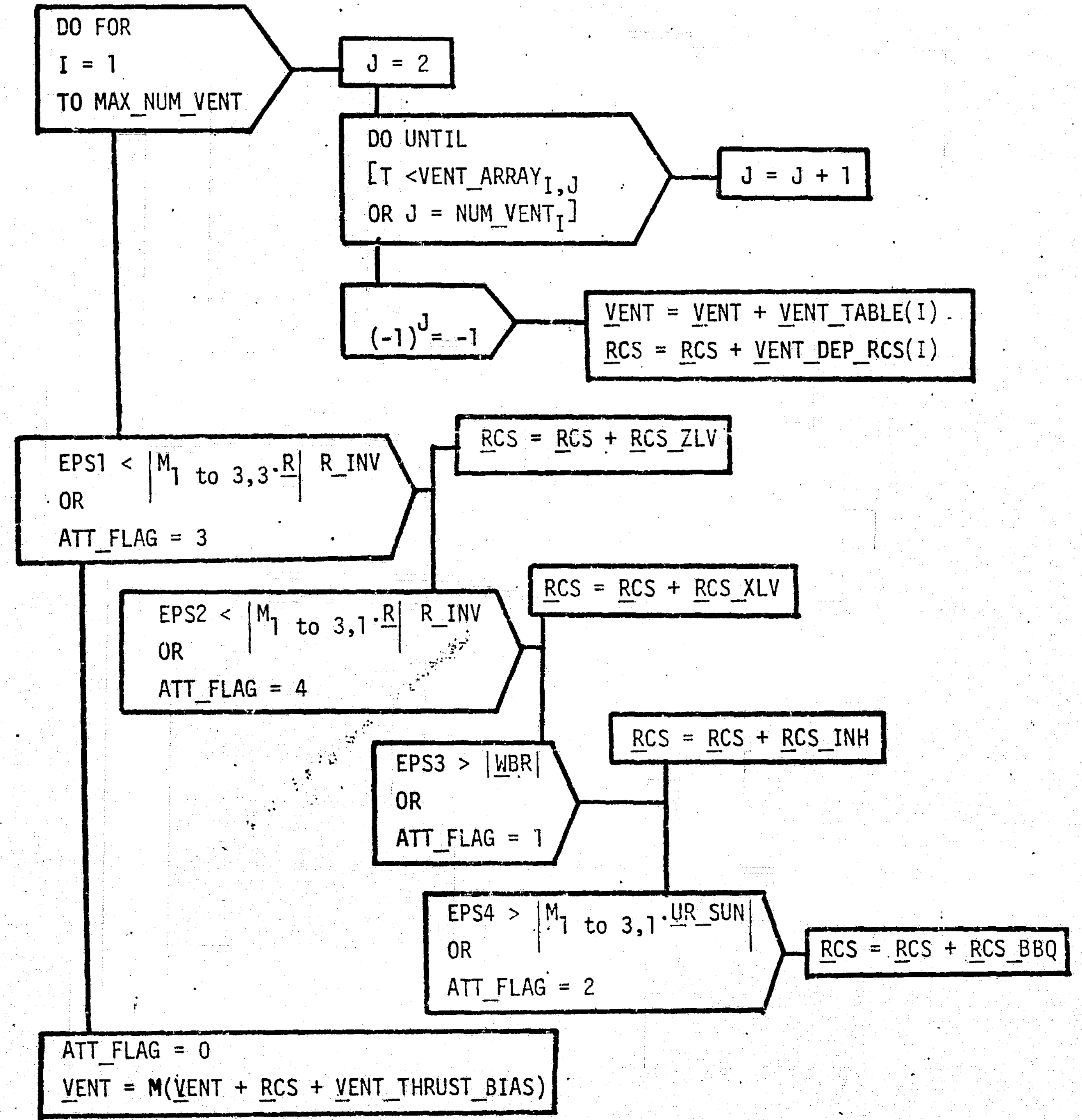
IWR CODE

$$T\_INITIAL = ATT\_ARRAY_{1,J-1}$$
$$EV_1 = ATT\_ARRAY_{6,J-I}$$
$$EV_2 = ATT\_ARRAY_{7,J-1}$$
$$EV_3 = ATT\_ARRAY_{8,J-1}$$
$$\underline{EV} = M\ \underline{EV}$$
$$HANG = 0.5\ ATT\_ARRAY_{9,J-1}(T-T\_INITIAL)$$
$$SQ = COS(HANG)$$
$$\underline{VQ} = SIN(HANG)\ \underline{EV}$$

$$M\_TEMP = \begin{bmatrix} 0 & -VQ_3 & VQ_2 \\ VQ_3 & 0 & -VQ_1 \\ -VQ_2 & VQ_1 & 0 \end{bmatrix}$$

$$M = [(2.SQ^2 - 1.)\ ID\_MATRIX\_3X3 + 2.\ \underline{VQ}\ \underline{VQ}^T + 2.SQ\ M\_TEMP]\ M$$

ACCEL_ONORBIT_VENT_AND_THRUST CODE



ONORBIT_DENSITY CODE

ALT = H_ELLIPSOID (R)
SDEC = SDEC R_INV R_3
CDEC2 = CDEC1 R_INV R_2
CDEC1 = CDEC1 R_INV R_1
SGAM1 = SIN_SOL_RA C_MX_AN + COS_SOL_RA S_MX_AN
CGAM1 = COS_SOL_RA C_MX_AN - SIN_SOL_RA S_MX_AN
SGAM2 = SIN_SOL_RA C_MN_AN + COS_SOL_RA S_MN_AN
CGAM2 = COS_SOL_RA C_MN_AN - SIN_SOL_RA S_MN_AN
COS_PSI_1 = SDEC + CGAM1 CDEC1 + SGAM1 CDEC2
COS_PSI_1 = DIURN_EFF_5 (1. + COS_PSI_1)$^{\text{CORR\_POWER\_1}}$
COS_PSI_2 = -SDEC + CGAM2 CDEC1 + SGAM2 CDEC2
COS_PSI_2 = DIURN_EFF_6 (1. + COS_PSI_2)$^{\text{CORR\_POWER\_2}}$
DAY_OF_ YEAR = T/86400.
I = 1

DO UNTIL DAY_OF_YEAR $\leq$ 10. I — I = I + 1

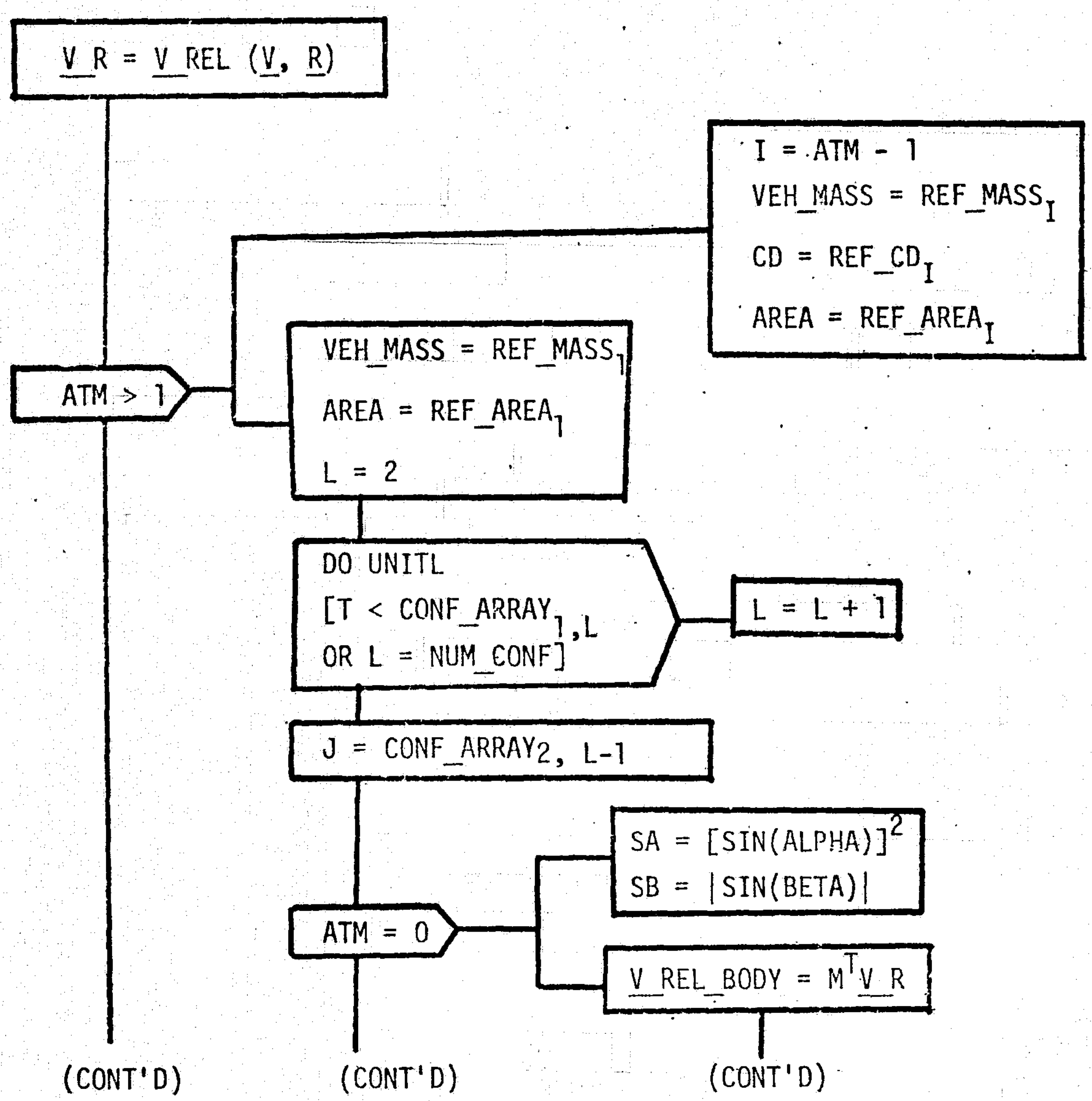
DAY_ONE = 10. (I - 1)

K1 = 1. +(ALT + RAD_EFF) SOL_RAD_EMIT_CORRECT
K2 = 1. +(ALT + DIURN_EFF_1 + DIURN_EFF_2 EXP{-[(ALT + DIURN_EFF_3)/DIURN_EFF_4]^2})(COS_PSI_1 + COS_PSI_2)
K3 = 1. + .1 (ALT + ANNUAL_EFF)[(DAY_OF_YEAR - DAY_ONE)(DOY_EFF$_{I+1}$-DOY_EFF$_I$) + 10. DOY_EFF$_I$]
K4 = 1. + (ALT + MAGN_EFF) GEOMAG_DISTURB_CORRECT
RHO = K1 K2 K3 K4 NIGHT_PROF_1 EXP[NIGHT_PROF_2 (ALT + NIGHT_PROF_3)$^{1/2}$]

H_ELLIPSOID (FUNCTION)

$$\text{H-EELIPSOID}(\underline{R}) = |\underline{R}| - (1 - \text{ELLIPT})\ \text{EARTH\_RADIUS\_EQUATOR}/\sqrt{1 + ((1 - \text{ELLIPT})^{2} - 1)(1 - (\text{UNIT}(\underline{R})\cdot\underline{\text{E}}\text{ARTH\_POLE})^{2})}$$

ACCEL_ONORBIT_DRAG CODE



ACCEL_ONORBIT_DRAG CODE (CONCLUDED)

$$|V\_REL\_BODY_3| \le EPS\_VRB$$

$$SA = 0.$$

$$SA = |V\_REL\_BODY_3|^2/(V\_REL\_BODY_1^2 + V\_REL\_BODY_3^2)$$

$$SB = |V\_REL\_BODY_2|/|\underline{V\_R}|$$

$$S2B = 2.\ SB\ SQRT(1. - SB^2)$$

$$CD = \left(CDF_J + CDN_J\ SA^{EXP\_SHAPE\_FACTOR_J}\right)(1. - SB) + CDS_J\ SB + CDA_J\ S2B\ SA$$

$$\underline{D} = -.5\ CD\ RHO\ AREA\ |\underline{V\_R}|\ \underline{V\_R}/VEH\_MASS$$

V_REL (FUNCTION

$$\boxed{\underline{V}\_REL(\underline{V}, \underline{R}) = \underline{V} - EARTH\_RATE\ (\underline{E}ARTH\_POLE\ X\ \underline{R})}$$

NAV_RENDEZVOUS

SNAP IMU (V_CURRENT_FILT, T_CURRENT_FILT)

SNAP REND_RADAR (Q_RR_SHFT, Q_RR_TRUN, Q_RR_RNG, Q_RR_RNG_DOT, RNG_DATA_GOOD, RDOT_DATA_GOOD, RR_ANGLE_DATA_GOOD, M_M50_TO_BODY_RR, T_REND_RADAR)

SNAP STAR_TRACKER (Q_ST_HORIZ, Q_ST_VERT, N_ST_IN_USE, ST_DATA_GOOD, M_M50_TO_BODY_ST, T_STAR_TRACKER)

SNAP COAS (Q_COAS_HORIZ, Q_COAS_VERT, N_COAS_IN_USE, COAS_DATA_GOOD, M_M50_TO_BODY_COAS, T_COAS)

CALL: ONORBIT_REND_R_V_STATE_PROP

CALL:
ONORBIT_REND_BIAS_AND_COV_PROP

EXECUTE:
REND_SENSOR_SELECT CODE

CALL:
ONORBIT_REND_AUTO_INFLIGHT_UPDATE

EXECUTE:
REND_NAV_SENSOR_INIT CODE

(CONT'D)

ORIGINAL PAGE IS OF POOR QUALITY

NAV_RENDEZVOUS (CONCLUDED)

(CONT'D)

DO_RR_ANGLE_NAV

CALL: RR_ANGLE_NAV
RR_ANGLE_MARK_NUM = RR_ANGLE_MARK_NUM + 1

DO_RRDOT_NAV

CALL: RRDOT_NAV
RRDOT_MARK_NUM = RRDOT_MARK_NUM + 1

DO_ST_ANGLE_NAV

CALL: ANGLE_NAV
IN LIST: T_STAR_TRACKER, M_BODY_TO_ST N_ST_IN_USE M_M50_TO_BODY_ST, VAR_ST_HORIZ, Q_ST_HORIZ, VAR_ST_VERT, Q_ST_VERT, ST_DATA_GOOD, ST_ANGLE_EDIT_OVERRIDE, ST_ANGLES_STAT

ST_MARK_NUM = ST_MARK_NUM + 1

DO_COAS_ANGLE_NAV

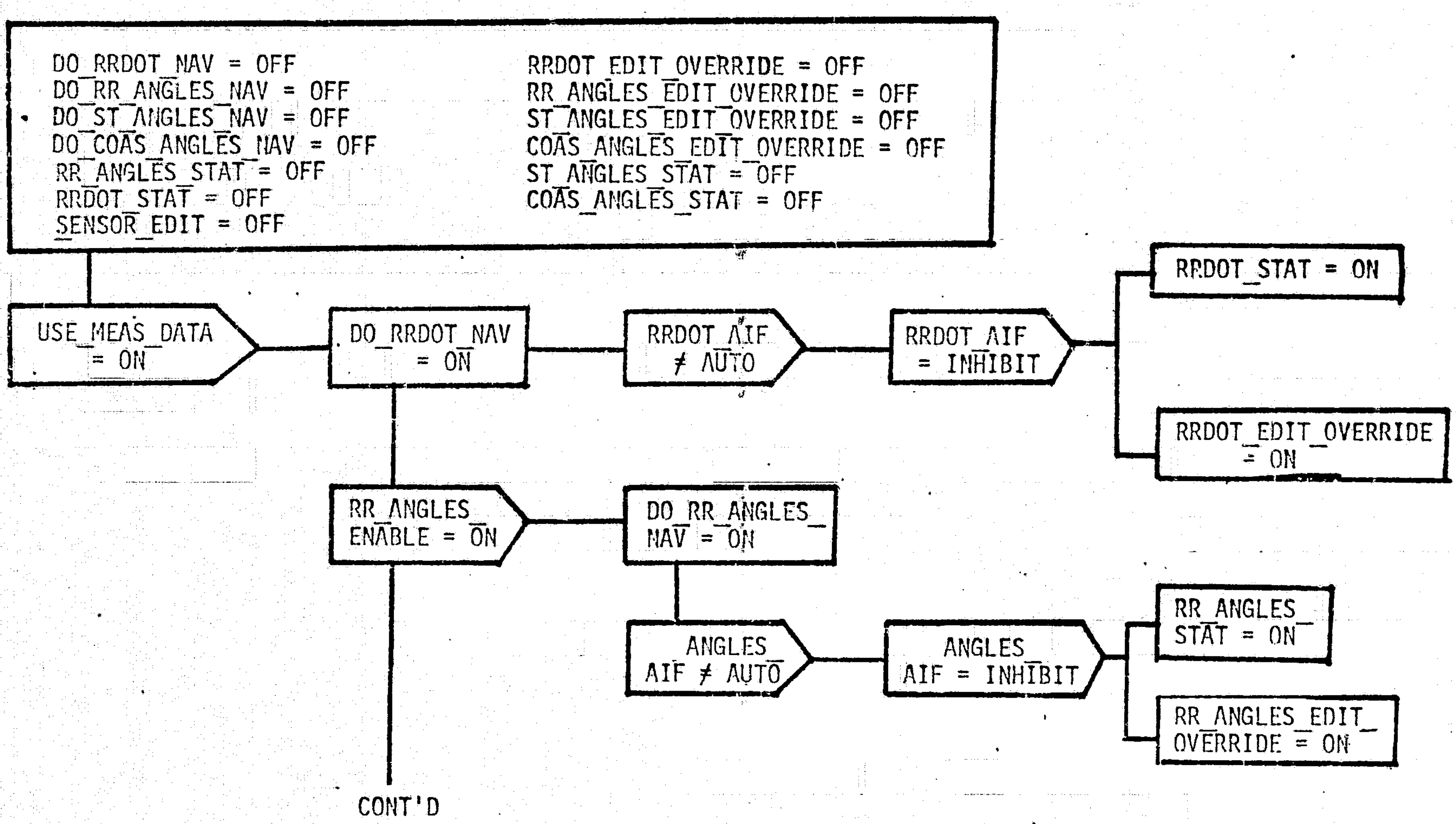
CALL: ANGLE_NAV
IN LIST: T_COAS, M_BODY_TO_COAS N_COAS_IN_USE M_M50_TO_BODY_COAS, VAR_COAS_HORIZ, Q_COAS_HORIZ, VAR_COAS_VERT, Q_COAS_VERT, COAS_DATA_GOOD, COAS_ANGLE_EDIT_OVERRIDE, COAS_ANGLES_STAT

COAS_MARK_NUM = COAS_MARK_NUM + 1

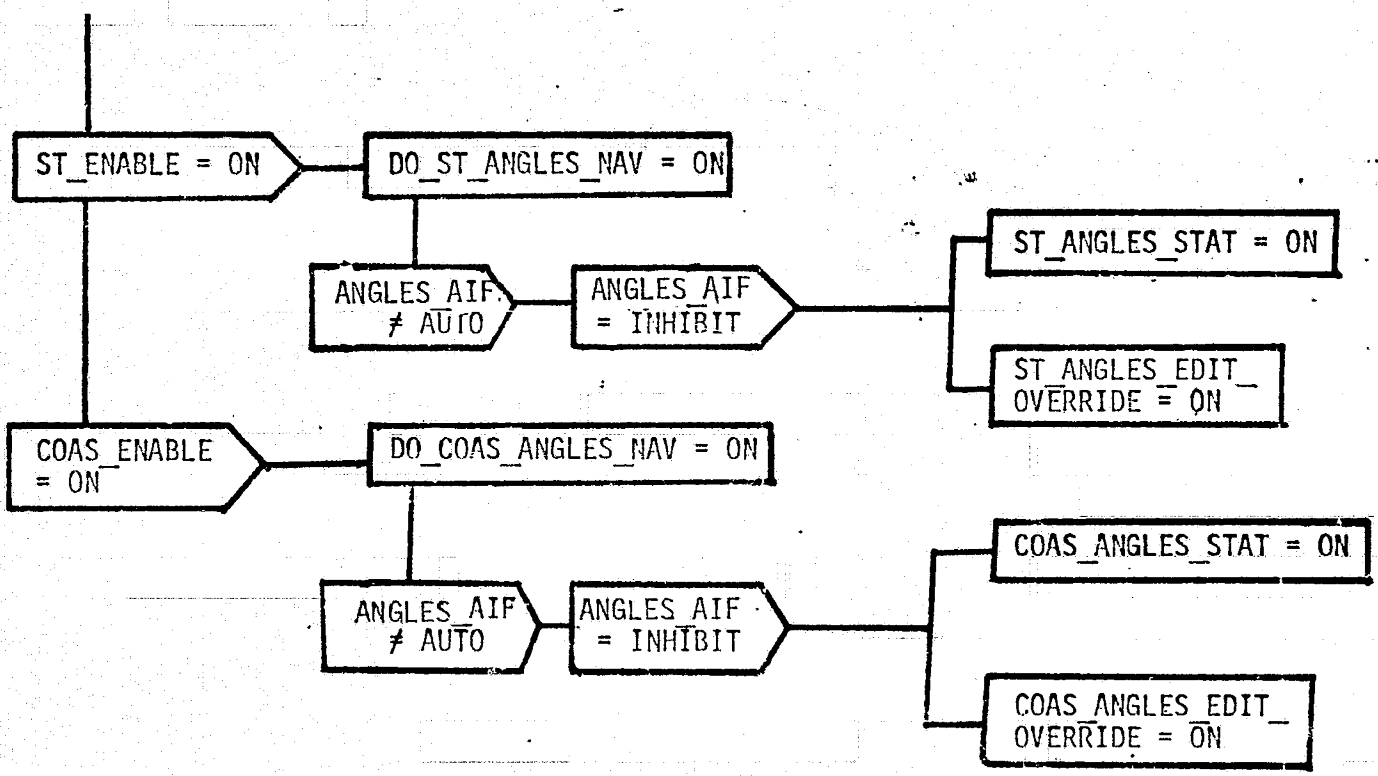
R_RESET = R_FILT, V_RESET = V_FILT, T_RESET = T_LAST_FILT
R_TV_RESET = R_TV, V_TV_RESET = V_TV, V_IMU_RESET = V_LAST_FILT,
FILT_UPDATE = ON

EXECUTE MEAS_PROCESSING_STATISTICS_REND (CODE)

REND_SENSOR_SELECT CODE



REND_SENSOR_SELECT CODE (CONCLUDED)



REND_NAV_SENSOR_INIT (CODE)

DO_RRDOT_NAV = ON
AND
DO_RRDOT_NAV_LAST = OFF

EXECUTE: RRDOT_SETUP CODE

N_ACCEPT$_{3 \text{ TO } 4}$ = 0, N_REJECT$_{3 \text{ TO } 4}$ = 0
SEQ_ACCEPT$_{3 \text{ TO } 4}$ = 0, SEQ_REJECT$_{3 \text{ TO } 4}$ = 0

DO_RR_ANGLES_NAV = ON
AND
DO_RR_ANGLES_NAV_LAST = OFF

EXECUTE: RR_ANGLES_SETUP CODE

N_ACCEPT$_{1 \text{ to } 2}$ = 0, N_REJECT$_{1 \text{ to } 2}$ = 0
SEQ_ACCEPT$_{1 \text{ to } 2}$ = 0, SEQ_REJECT$_{1 \text{ to } 2}$ = 0

DO_ST_ANGLES_NAV = ON
AND
DO_ST_ANGLES_NAV_LAST = OFF

EXECUTE: ST_ANGLES_SETUP CODE

N_ACCEPT$_{1 \text{ to } 2}$ = 0, N_REJECT$_{1 \text{ to } 2}$ = 0
SEQ_ACCEPT$_{1 \text{ to } 2}$ = 0, SEQ_REJECT$_{1 \text{ to } 2}$ = 0

DO_COAS_ANGLES_NAV = ON
AND
DO_COAS_ANGLES_NAV_LAST = OFF

EXECUTE: COAS_ANGLES_SETUP CODE

N_ACCEPT$_{1 \text{ to } 2}$ = 0, N_REJECT$_{1 \text{ to } 2}$ = 0
SEQ_ACCEPT$_{1 \text{ to } 2}$ = 0, SEQ_REJECT$_{1 \text{ to } 2}$ = 0

DO_RRDOT_NAV_LAST = DO_RRDOT_NAV
DO_RR_ANGLES_NAV_LAST = DO_RR_ANGLES_NAV
DO_ST_ANGLES_NAV_LAST = DO_ST_ANGLES_NAV
DO_COAS_ANGLES_NAV_LAST = DO_COAS_ANGLES_NAV

RRDOT_SETUP (CODE)

$E_{18 \text{ to } 19,\ 1 \text{ to } 19} = 0$

$E_{1 \text{ to } 17,\ 18 \text{ to } 19} = 0$

$TAU\_SENS_{3 \text{ to } 4} = \underline{TAU}\_RRDOT$

$SENSOR\_BIAS_{3 \text{ to } 4} = 0.0$

$VAR\_SENS\_DT_{3 \text{ to } 4} = \underline{VAR}\_RRDOT\_DT$

DO FOR I = 1 to 2 → $E_{17 + I,\ 17 + I} = VAR\_RRDOT_I$

RR_ANGLES_SETUP (CODE)

$E_{16 \text{ to } 17,\ 1 \text{ to } 19} = 0.0$

$E_{1 \text{ to } 19,\ 16 \text{ to } 17} = 0.0$

$TAU\_SENS_{1 \text{ to } 2} = TAU\_RR\_ANGLES$

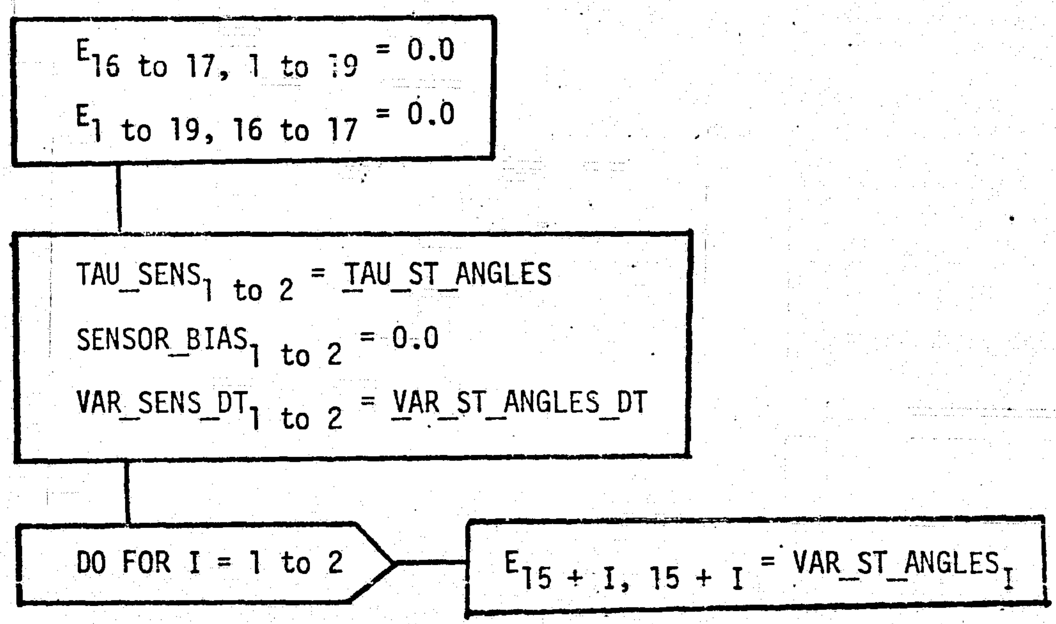
$SENSOR\_BIAS_{1 \text{ to } 2} = 0.0$

$VAR\_SENS\_DT_{1 \text{ to } 2} = VAR\_RR\_ANGLES\_DT$

DO FOR I = 1 to 2

$E_{15 + I,\ 15 + I} = VAR\_RR\_ANGLES_I$

ST_ANGLES_SETUP (CODE)



C.6

B-38

COAS_ANGLES_SETUP (CODE)

$E_{16 \text{ to } 17,\ 1 \text{ to } 19} = 0.0$

$E_{1 \text{ to } 19,\ 16 \text{ to } 17} = 0.0$

$\text{TAU\_SENS}_{1 \text{ to } 2} = \text{TAU\_COAS\_ANGLES}$

$\text{SENSOR\_BIAS}_{1 \text{ to } 2} = 0.0$

$\text{VAR\_SENS\_DT}_{1 \text{ to } 2} = \text{VAR\_COAS\_ANGLES\_DT}$

DO FOR I = 1 to 2

$E_{15 + I,\ 15 + I} = \text{VAR\_COAS\_ANGLES}_I$

B-39

RR_ANGLE_NAV

RR_ANGLE DATA_GOOD

DELTAT_GO = T_CURRENT_FILT-T_REND_RADAR

CALL: REND_NAV_INTERP

M_M50_TO_SENSOR = M_BODY_TO_RR M_M50_TO_BODY_RR

CALL: REND_ANGLE_PARTIALS
IN LIST: M_M50_TO_SENSOR$_{3,\ 1\ \text{to}\ 3}$

VAR = VAR_SHFT, B_{16} = 1
MANUAL_EDIT_OVERRIDE = RR_ANGLES_EDIT_OVERRIDE
STAT_FLAG = RR_ANGLES_STAT

SHFT = ARCTAN (U_M$_2$/U_M$_1$) + BIAS_SENSOR$_1$
DELQ = Q_RR_SHFT - SHFT

CALL: REND_NAV_FILTER

SENSOR_EDIT$_1$ = EDIT_FLAG
SENSOR_RESID_TEST$_1$ = RESID_TEST
SENSOR_DELQ$_1$ = DELQ

CALL: REND_NAV_INTERP

(CONT'D)

ORIGINAL PAGE IS
OF POOR QUALITY

RR_ANGLE_NAV (CONCLUDED)

CALL: REND_ANGLE_PARTIALS

IN LIST: UNIT (R_TV_RESID - R_RESID) X M_M50_TO_SENSOR$_{3,\ 1\ \text{to}\ 3}$)

VAR = VAR_TRUN, B_{17} = 1.

TRUN = ARCSIN (UM_3) + BIAS_SENSOR$_2$

DELQ = Q_RR_TRUN - TRUN

CALL: REND_NAV_FILTER

SENSOR_EDIT$_2$ = EDIT_FLAG

SENSOR_RESID_TEST$_2$ = RESID_TEST

SENSOR_DELQ$_2$ = DELQ

B-40A

REND_ANGLE_PARTIALS

IN LIST: I_N

$$\underline{R}\_RHO = \underline{R}\_TV\_RESID - \underline{R}\_RESID$$

$$\underline{RHO}\_PLANE = \underline{R}\_RHO - (\underline{R}\_RHO \cdot \underline{I}\_N)\ \underline{I}\_N$$

$$\underline{B}\_TEMP = UNIT\ (\underline{RHO}\_PLANE\ X\ \underline{I}\_N)/|\underline{RHO}\_PLANE|$$

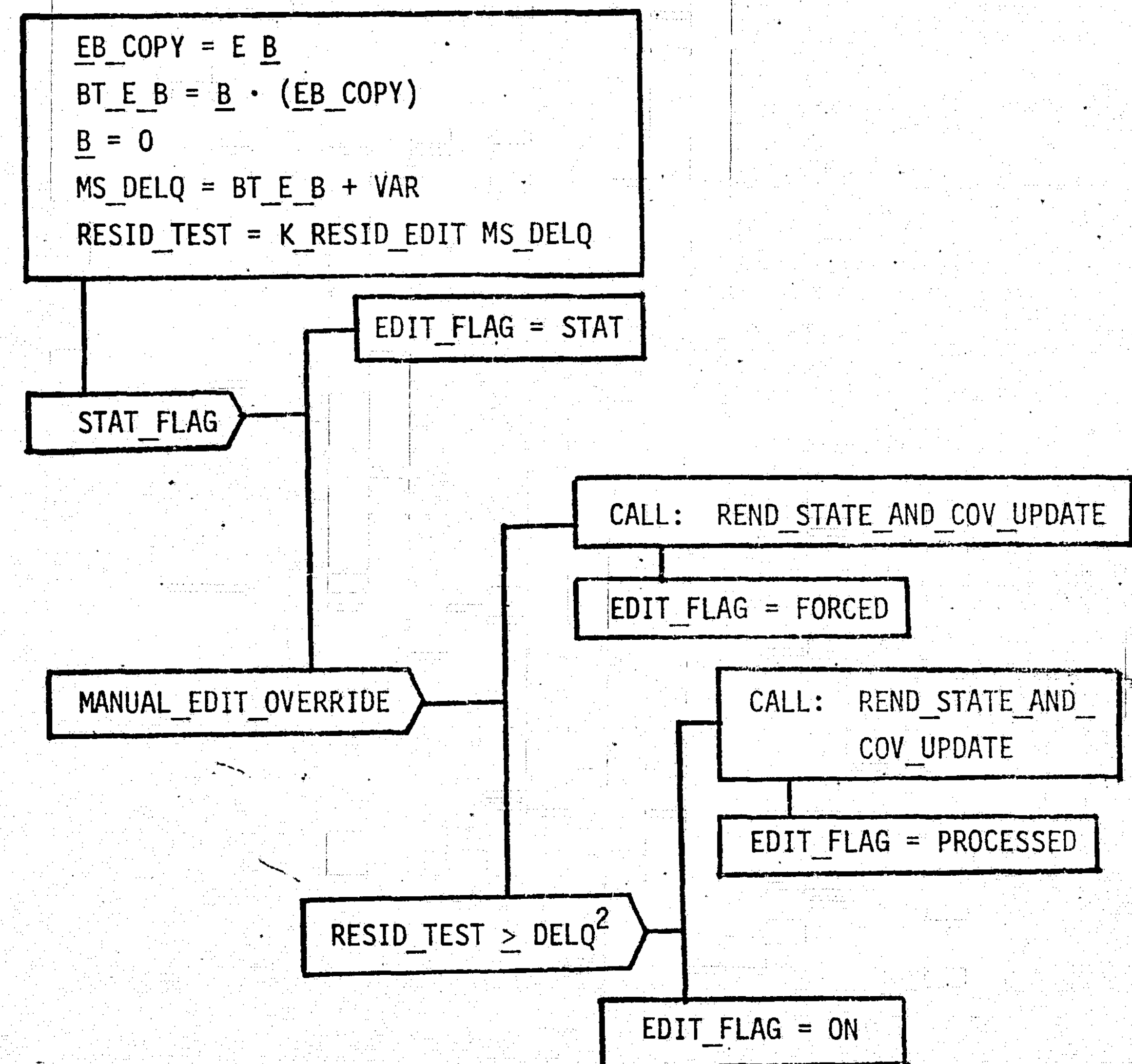
$$B_{1\text{ to }6} = (PHI\_PATCH_{1\text{ to }3,\ 1\text{ to }6})^T\ \underline{B}\_TEMP$$

$$B_{10\text{ to }15} = -\ (PHI\_REND\_PATCH_{1\text{ to }3,\ 1\text{ to }6})^T\underline{B}\_TEMP$$

$$B_{16\text{ to }17} = 0.$$

$$\underline{U}\_M = M\_M50\_TO\_SENSOR\ UNIT\ (\underline{R}\_RHO)$$

REND_NAV_FILTER



REND_STATE_AND_COV_UPDATE (CODE)

OMEGA = EB_COPY/MS_DELQ

E = E - OMEGA EB_COPY

R_FILT = R_FILT + $\text{OMEGA}_{1\text{ to }3}$ DELQ

V_FILT = V_FILT + $\text{OMEGA}_{4\text{ to }6}$ DELQ

VENT_THRUST_BIAS = VENT_THRUST_BIAS + $\text{OMEGA}_{7\text{ to }9}$ DELQ

R_TV = R_TV + $\text{OMEGA}_{10\text{ to }12}$ DELQ

V_TV = T_TV + $\text{OMEGA}_{13\text{ to }15}$ DELQ

SENSOR_BIAS = SENSOR_BIAS + $\text{OMEGA}_{16\text{ to }19}$ DELQ

B-43

REND_NAV_INTERP

CALL: ONORBIT_SV_INTERP
IN LIST: R_LAST, V_LAST, R_FILT, V_FILT, T_CURRENT_FILT, DV_FILT, DT_FILT, SENSOR_ID, DELTAT_GO, IGD, IGO, IDM, IVM, IATM
OUT LIST: R_RESID, V_RESID, A_RESID

CALL: MEAN_CONIC_PARTIAL_TRANSITION_MATRIX_6X6
IN LIST: R_FILT, V_FILT, TOT_ACC, R_RESID, V_RESID, A_RESID, - DELTAT_GO
OUT LIST: PHI_PATCH

CALL: ONORBIT_SV_INTERP
IN LIST: R_TV_LAST, V_TV_LAST, R_TV, V_TV, T_CURRENT_FILT, 0, DT_FILT, SENSOR_ID, DELTAT_GO, IGD, IGO, 1, 0, 3
OUT LIST: R_TV_RESID, V_TV_RESID, A_TV_RESID

CALL: MEAN_CONIC_PARTIAL_TRANSITION_MATRIX_6X6
IN LIST: R_TV, V_TV, G_TV, R_TV_RESID, V_TV_RESID, A_TV_RESID, - DELTAT_GO
OUT LIST: PHI_REND_PATCH

ONORBIT_SV_INTERP

IN LIST: R_ONE, V_ONE, R_TWO, V_TWO, T_TWO, V_IMU_DIF, T_DIF, SENSOR_ID, DTGO, IGD, IGO, IDM, IVM, IATM

OUT LIST: R_RESID, V_RESID, A_RESID

DELTAT = -DTGO

IF |DELTAT| ≤ EPS_TIME SENSOR_ID

R_RESID = R_TWO
V_RESID = V_TWO
T_RESID = T_TWO

R_TWO_INV = 1./|R_TWO|
SMA = 1./[1./|R_ONE| + R_TWO_INV
-(V_ONE • V_ONE + V_TWO •
V_TWO)/(2.EARTH_MU)]
C1 = SQRT(SMA)/SQR_EMU
D_TWO = R_TWO • V_TWO C1/SMA
T_RESID = T_TWO + DELTAT

CALL: F_AND_G
IN LIST: SMA, DELTAT, C1, R_TWO, 0., 0., 0., R_TWO_INV, 0., V_TWO, D_TWO, 0.
OUT LIST: F, G, FDOT, GDOT, S0, S1, S2, S3, R_RESID, R_FIN_INV, THETA

V_RESID = FDOT R_TWO + GDOT V_TWO

A_RESID = -EARTH_MU R_RESID/|R_RESID|^3 + ACCEL_PERT_ONORBIT (IGD, IGO, IDM, IVM, IATM, R_RESID, V_RESID, T_RESID) + V_IMU_DIF/T_DIF

RRDOT_NAV

RNG_DATA_GOOD → CALL: REND_NAV_INTERP

R_RHO = R_TV_RESID - R_RESID

R_RHO_MAG = |R_RHO|

I_RHO = R_RHO/R_RHO_MAG

Q_PRIME = R_RHO_MAG + $SENSOR\_BIAS_3$

$B_{1\ to\ 6} = -(PHI\_PATCH_{1\ to\ 3,\ 1\ to\ 6})^T\ I\_RHO$

$B_{10\ to\ 15} = (PHI\_REND\_PATCH_{1\ to\ 3,\ 1\ to\ 6})^T\ I\_R$

$B_{18} = 1.0$

DELQ = Q_RR_RNG - Q_PRIME

$VAR = (SIG\_RR\_RNG + SLOPE\_SIG\_RR\_RNG\ R\_RHO\_MAG)^2$

VAR < VAR_RR_RNG_MIN → VAR = VAR_RR_RNG_MIN

MANUAL_EDIT_OVERRIDE = RRDOT_EDIT_OVERRIDE

STAT_FLAG = RRDOT_STAT

CALL: REND_NAV_FILTER

$SENSOR\_EDIT_3$ = EDIT_FLAG

$SENSOR\_RESID\_TEST_3$ = RESID_TEST

$SENSOR\_DELQ_3$ = DELQ

(CONT'D)

RRDOT_NAV (CONCLUDED)

RDOT_DATA_GOOD

CALL: REND_NAV_INTERP

$\underline{U}$_RDOT = ($\underline{V}$_TV_RESID − $\underline{V}$_RESID)/R_RHO_MAG

$B_{1\text{ to }3}$ = $\underline{I}$_RHO X($\underline{I}$_RHO X $\underline{U}$_RDOT)

$B_{10\text{ to }12}$ = $-B_{1\text{ to }3}$

$B_{4\text{ to }6}$ = −$\underline{I}$_RHO

$B_{10\text{ to }15}$ = $-B_{4\text{ to }6}$

$B_{1\text{ to }6}$ = PHI_PATCH^T $B_{1\text{ to }6}$

$B_{10\text{ to }15}$ = PHI_REND_PATCH^T $B_{10\text{ to }15}$

Q_PRIME = $\underline{R}$_RHO · $\underline{U}$_RDOT + SENSOR_BIAS$_4$

VAR = VAR_RANGE_DOT

DELQ = Q_R_RNG_DOT − Q_PRIME

CALL: REND_NAV_FILTER

SENSOR_EDIT$_4$ = EDIT_FLAG

SENSOR_RESID_TEST$_4$ = RESID_TEST

SENSOR_DELQ$_4$ = DELQ

ANGLE_NAV

IN LIST: T_ANGLES, M_M50_TO_SENSOR, VAR_HORIZ, Q_HORIZ, VAR_VERT, Q_VERT, ANGLE_DATA_GOOD, MANUAL_EDIT_OVERRIDE, STAT_FLAG

ANGLE_DATA_GOOD

DELTAT_GO = T_CURRENT_FILT-T_ANGLES

CALL: REND_NAV_INTERP

CALL: REND_ANGLE_PARTIALS

IN LIST: $M\_M50\_TO\_SENSOR_{2,1 \text{ to } 3}$

VAR = VAR_VERT

$B_{16} = 1.0$

$VERT = ARCTAN(U\_M_1/U\_M_3) + BIAS\_SENSOR_1$

DELQ = Q_VERT - VERT

CALL: REND_NAV_FILTER

$SENSOR\_DELQ_2 = DELQ$

$SENSOR\_RESID\_TEST_2 = RESID\_TEST$

$SENSOR\_EDIT_2 = EDIT\_FLAG$

(CONT'D)

ANGLE_NAV (CONCLUDED)

(CONT'D)

CALL: REND_NAV_INTERP

CALL: REND_ANGLE_PARTIALS
IN LIST: M_M50_TO_SENSOR$_{1,\ 1\ \text{to}\ 3}$

VAR = VAR_HORIZ

B$_{17}$ = 1.0
HORIZ = ARCTAN(U_M$_2$/U_M$_3$) + BIAS_SENSOR$_2$
DELQ = Q_HORIZ - HORIZ

CALL: REND_NAV_FILTER

SENSOR_DELQ$_1$ = DELQ
SENSOR_RESID_TEST$_1$ = RESID_TEST
SENSOR_EDIT$_1$ = EDIT_FLAG

LUNAR_EPHEM

IN LIST: T

OUT LIST: UR_MOON

T1 = T/3155760000.

OMEGA = OM_1 + T1 OM_2

EPSILON = SOL_PARAM_ZERO$_2$ + T1 SOL_PARAM_FIRST$_2$

MOON_AUXIL = MOON_PARAM_ZERO + T1 MOON_PARAM_FIRST

C_OM = COS(OMEGA)

S_OM = SIN(OMEGA)

C_EPS = COS(EPSILON)

S_EPS = SIN(EPSILON)

INTERM$_1$ = SIN(MOON_AUXIL$_1$)

INTERM$_2$ = SIN(MOON_AUXIL$_3$ - MOON_AUXIL$_1$)

INTERM$_3$ = SIN(MOON_AUXIL$_3$)

THETA = MOON_AUXIL$_2$ + MOON_CONST·INTERM

C_TH = COS(THETA)

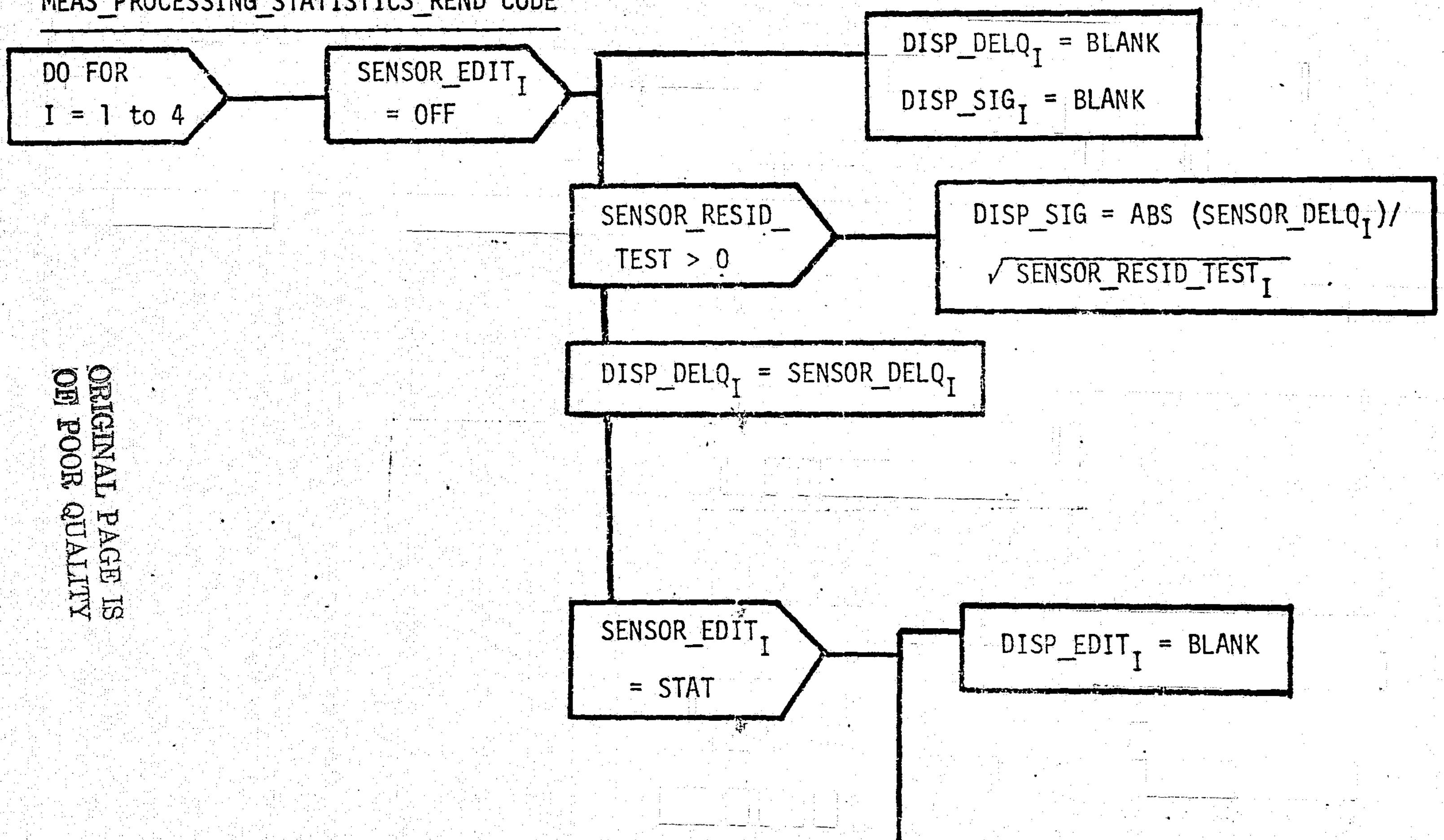
S_TH = SIN(THETA)

UR_MOON$_1$ = C_OM C_TH - S_OM C_INC S_TH

UR_MOON$_2$ = C_EPS S_OM C_TH + (C_EPS C_OM C_INC - S_EPS S_INC) S_TH

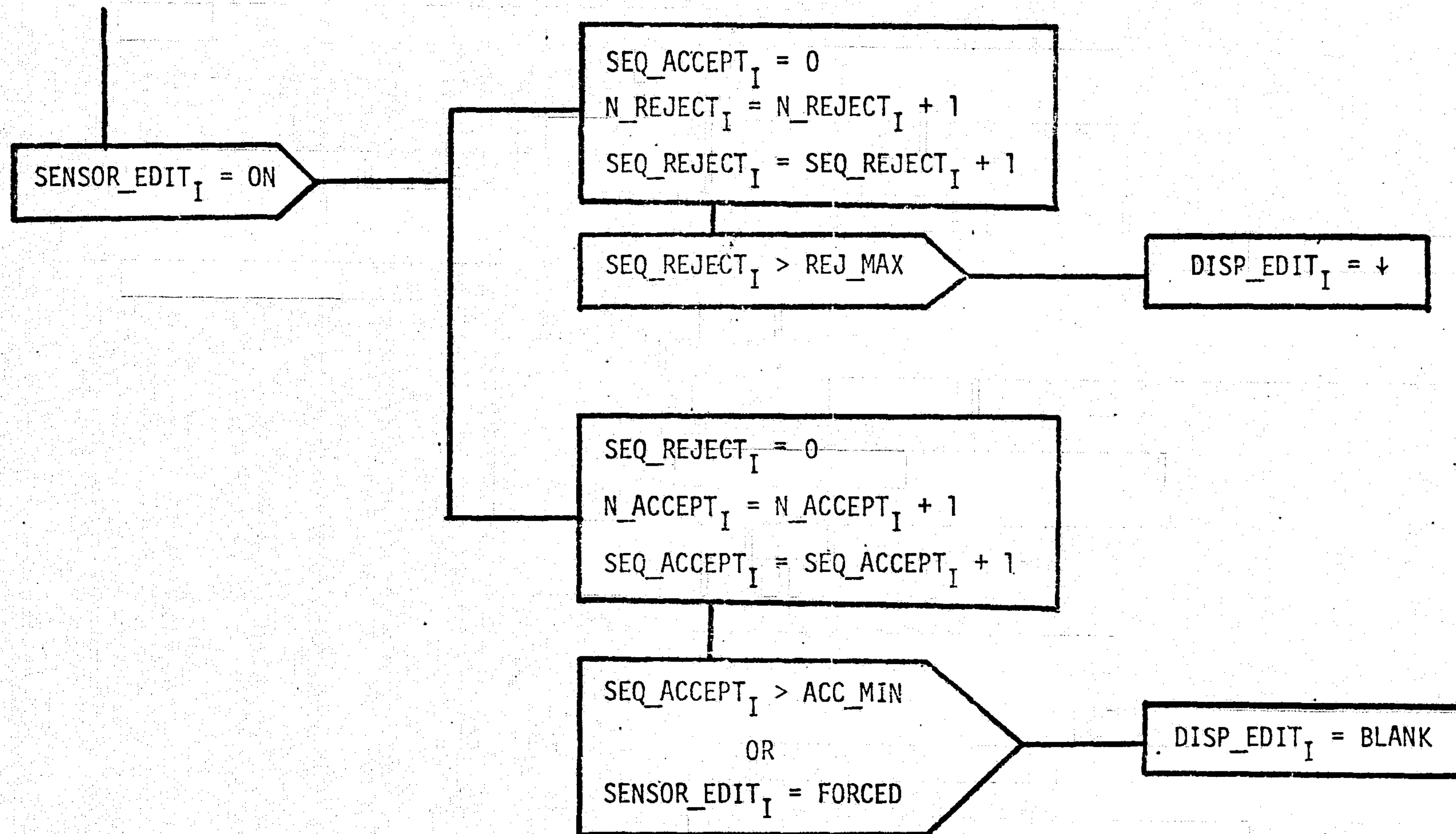
UR_MOON$_3$ = S_EPS S_OM C_TH + (S_EPS C_OM C_INC + C_EPS S_INC) S_TH

MEAS_PROCESSING_STATISTICS_REND CODE



(CONT'D)

MEAS PROCESSING_STATICS_REND (CODE), (concluded)



APPENDIX C

GENERAL REQUIREMENT PRINCIPAL FUNCTIONS AND COORDINATE

TRANSFORMATIONS FLOW CHARTS, VARIABLE NAMES, AND DESCRIPTIONS

CONTENTS

VARIABLES LIST DEFINITIONS

Code used for variable data type

S:	scalar
V(n):	vector (dimension)
M(n):	square matrix (dimension)
INT:	integer
BIT:	bit
CHAR:	character
STR:	structure
ARR:	array

Coordinate frame code and definition

Body: (structural)	x: parallel to the longitudinal axis (positive aft)
	y: completes right-hand system
	z: perpendicular to the x-axis, positive upward
EF	Earth-fixed coordinate system
M50:	Mean of 50 reference coordinate system
RW: (runway coordinates)	x: down runway centerline in direction of landing
	y: completes right-hand system
	z: down, normal to ellipsoid
TD: (topodetic coordinates)	x: north
	Y: east
	z: down, normal to ellipsoid
UVW	Quasi-inertial, right-handed Cartesian coordinate system
	u: along vehicle position vector (radial)
	v: normal to u, in orbit plane (downtrack)
	w: out of orbit plane, uxv=w, (crosstrack)

ORIGINAL PAGE IS OF POOR QUALITY

APPENDIX C VARIABLE LIST

VARIABLE NAME	DATA TYPE	INITIAL VALUE	COORD FRAME	VARIABLE DESCRIPTION
AM	INT	0		Flag (ON) to indicate the use of the Adams-Moulton integration technique
AM_TABLE	M(8,7)	0	M50	Table of derivatives required by the Adams-Moulton integrator
ATM	INT	0		Flag indicating vehicle attitude mode
CORR_COEF	ARR(8)	ILOAD		Array of morder coeficients used in the Adams-Moulton corrector
DELTA_T	S	0		Input integration step size for prediction or propagation
DERIV	ARR(7)	0	M50	Temporary storage for derivatives required for the Adams-Moulton integrator
DM	INT	0		Flag indicating if model for acceleration due to drag is to be used
DT_MAX	S	ILOAD		Maximum integration step size used for prediction
DT_STEP	S	0		Integration step size for prediction or propagation
GMD	INT	0		Flag indicating the degree of the gravitational potential model
GMO	INT	0		Flag indicating the order of the gravitational potential model

APPENDIX C VARIABLE LIST (Continued)

VARIABLE NAME	DATA TYPE	INITIAL VALUE	COORD FRAME	VARIABLE DESCRIPTION
I	INT			Counter
MORDER	INT	8		Order of the Adams-Moulton integrator
N_STEPS	INT	0		Number of integration steps in the prediction or propagation interval
PRED_COEF	ARR(8)	ILOAD		Array of morder coeficients used in the Adams-Moulton predictor
R_FIN	V(3)	0	M50	Orbiter or target position vector at T_FIN
R_IN	V(3)	0	M50	Orbiter or target position vector at T_IN
SUM	S	0		Temporary storage variable used in the Adams-Moulton integrator
T_CUR	S	0		Current integration time within the predictor or propagator
T_IN	S	0		Initial time input for onorbit prediction or propagation
V_FIN	V(3)	0	M50	Orbiter or target velocity vector at T_FIN
V_IN	V(3)	0	M50	Orbiter or target velocity vector at T_IN

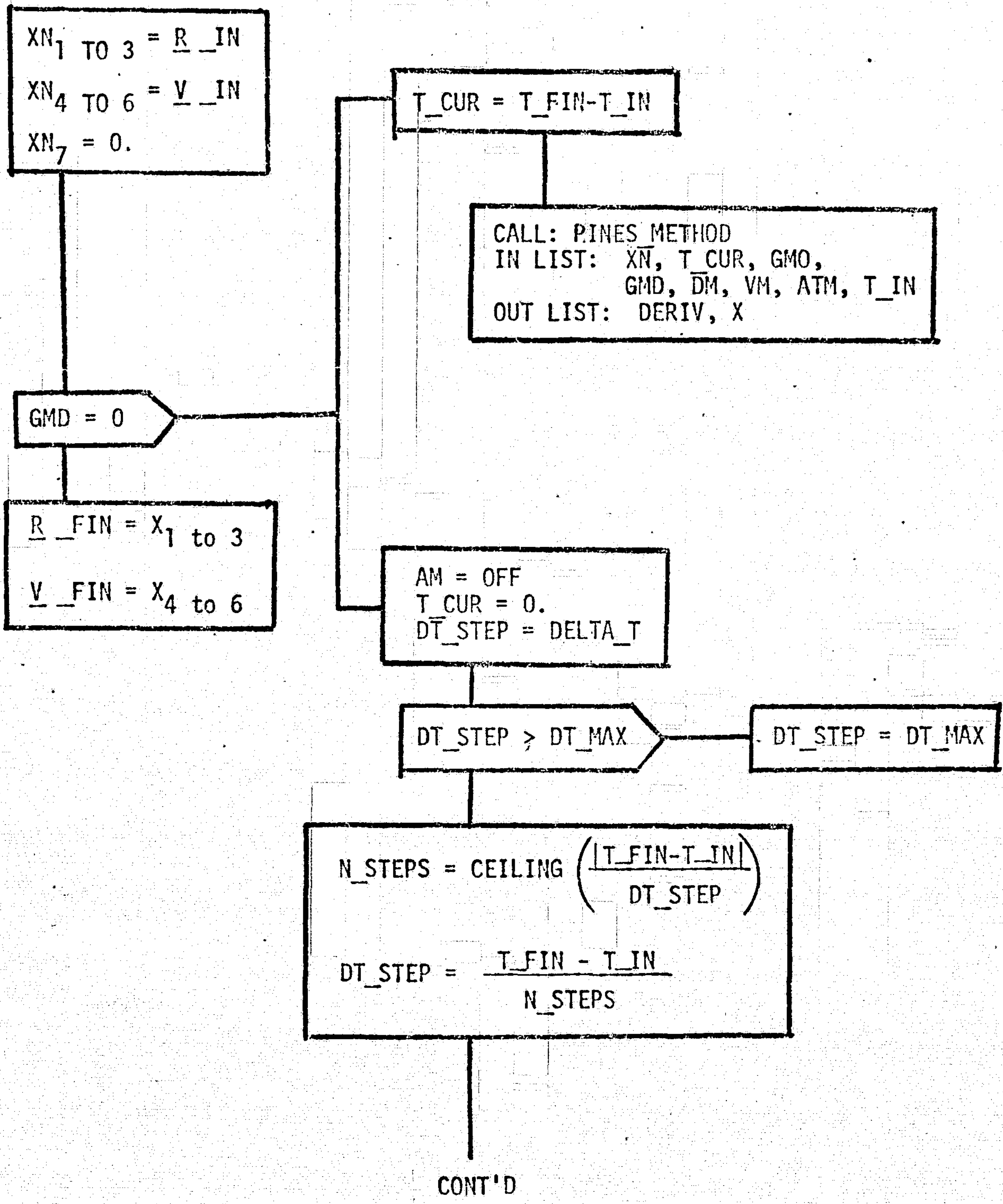
APPENDIX C. VARIABLE LIST (Continued)

VARIABLE NAME	DATA TYPE	INITIAL VALUE	COORD FRAME	VARIABLE DESCRIPTION
VM	INT	0		Flag indicating whether venting accelerations are to be modeled for prediction or propagation
X	ARR(6)	0	M50	Temporary array for the shuttle or target state vector
XN	ARR(7)	0	M50	Array of integrated initial conditions for onorbit prediction and propagation
XP	ARR(7)	0	M50	Temporary storage array of integrated initial conditions used in the Adams-Moulton integrator

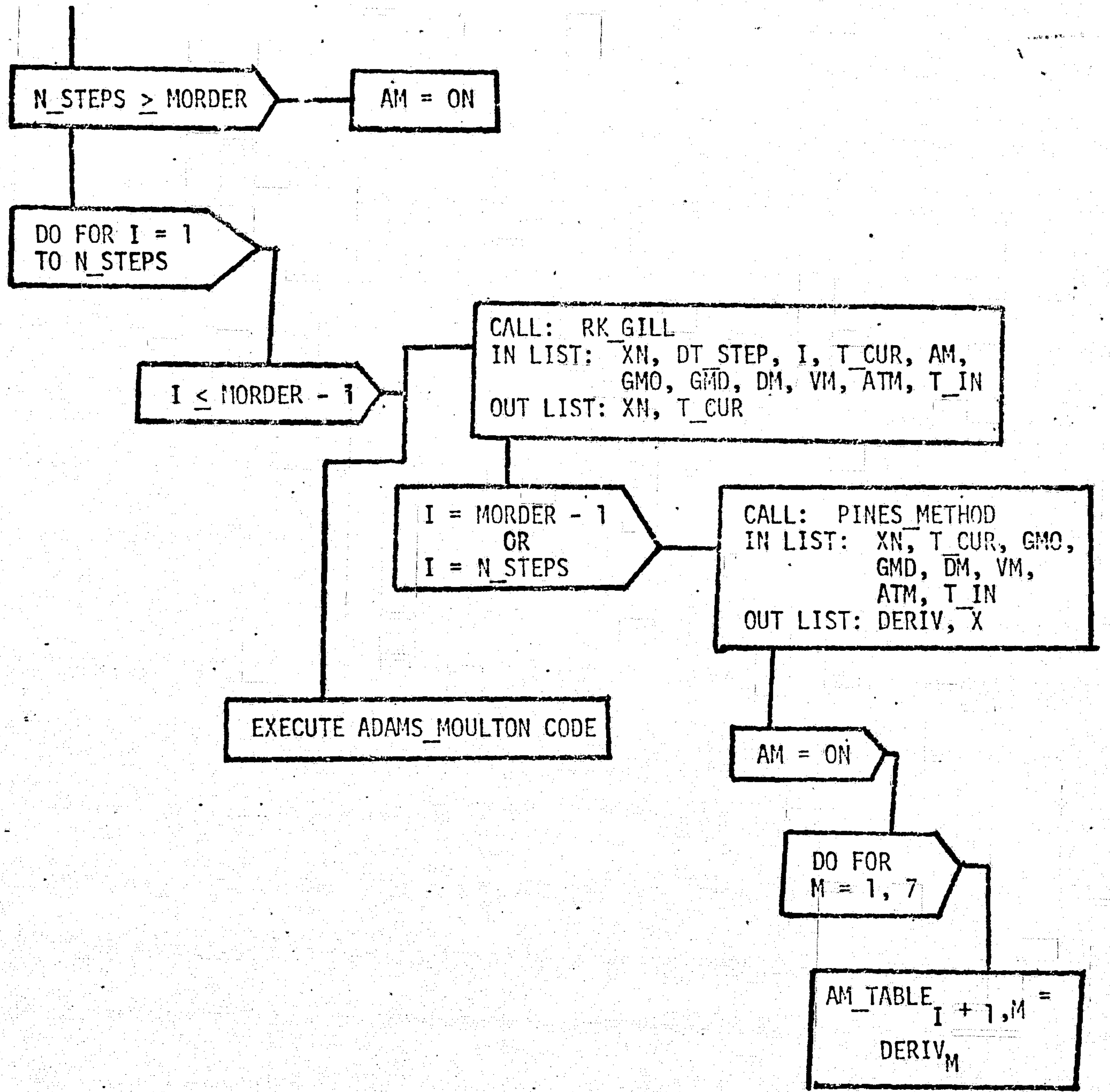
ONORBIT_PREDICT

IN LIST: GMD, GMO, DM, VM, ATM, DELTA_T, R _IN, V _IN, T_IN, T_FIN

OUT LIST: R _FIN, V _FIN

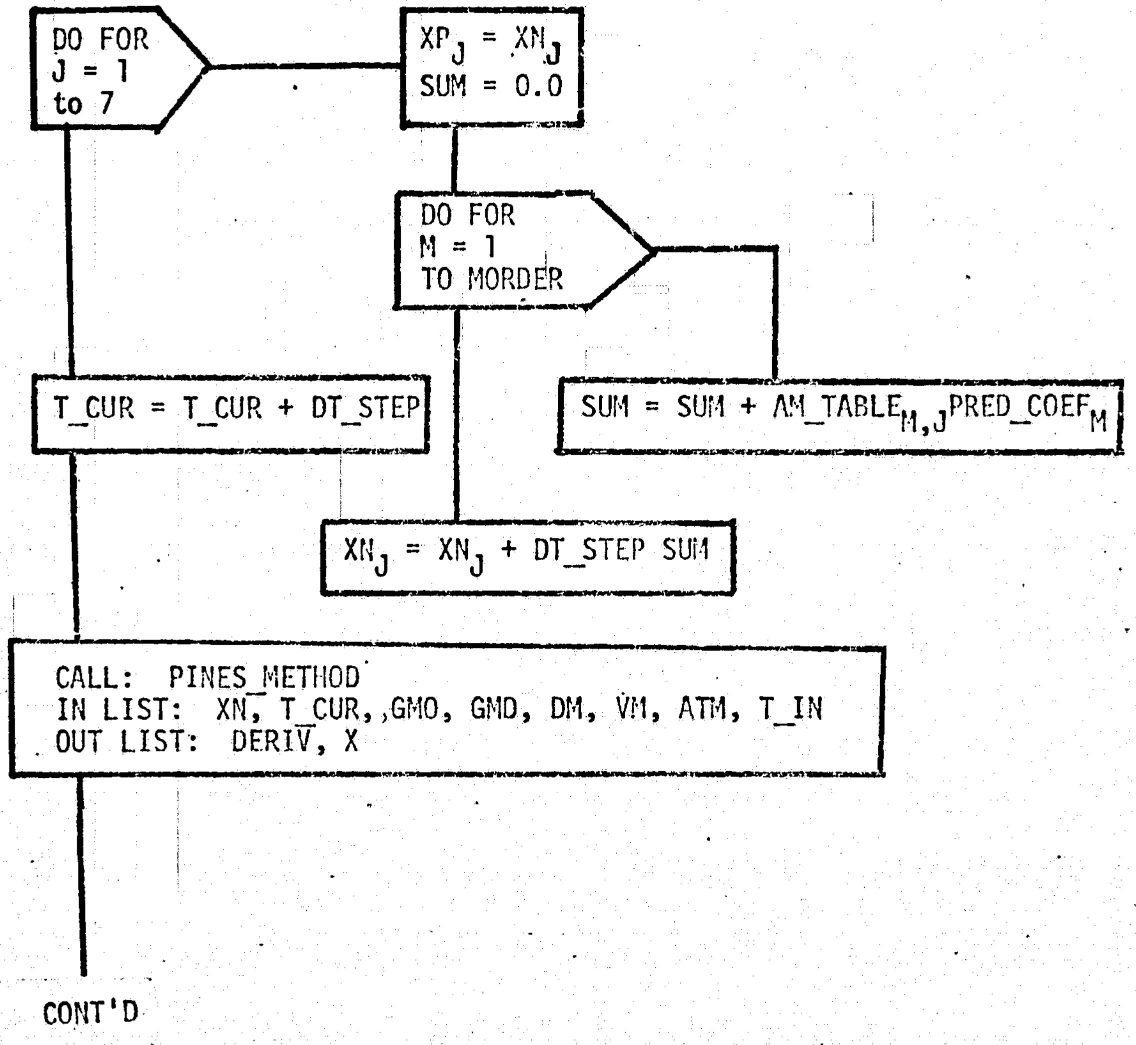


ONORBIT_PREDICT (CONCLUDED)

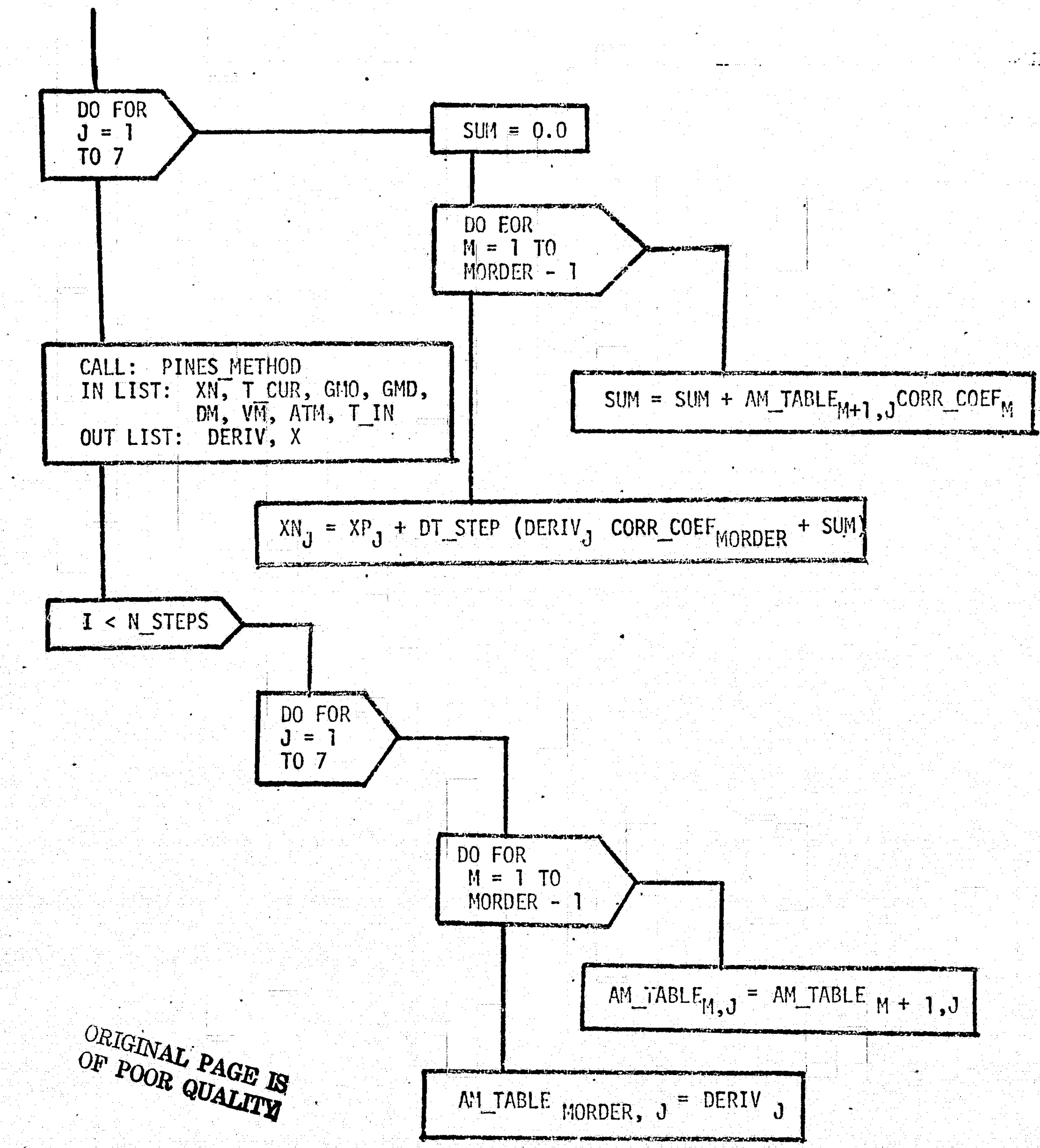


C.2-1A

ADAMS_MOULTON CODE



ADAMS_MOULTON CODE (CONCLUDED)



APPENDIX D

USER PARAMETER

FLOW CHARTS, VARIABLE NAMES,

AND DESCRIPTIONS

CONTENTS

VARIABLES LIST DEFINITIONS

Code used for variable data type

S:	scalar
V(n):	vector (dimension)
M(n):	square matrix (dimension)
INT:	integer
BIT:	bit
CHAR:	character
STR:	structure
ARR:	array

Coordinate frame code and definition

Body: (structural)	x:	parallel to the longitudinal axis (positive aft)
	y:	completes right-hand system
	z:	perpendicular to the x-axis, positive upward
EF		Earth-fixed coordinate system
M50:		Mean of 50 reference coordinate system
RW: (runway coordinates)	x:	down runway centerline in direction of landing
	y:	completes right-hand system
	z:	down, normal to ellipsoid
TD: (topodetic coordinates)	x:	north
	Y:	east
	z:	down, normal to ellipsoid
UVW		Quasi-inertial, right-handed Cartesian coordinate system
	u:	along vehicle position vector (radial)
	v:	normal to u, in orbit plane (downtrack)
	w:	out of orbit plane, uxv=w, (crosstrack)

APPENDIX D VARIABLE LIST

VARIABLE NAME	DATA TYPE	INITIAL VALUE	COORD FRAME	VARIABLE DESCRIPTION
A_SENSED	V(3)		M50	Ratio of difference of selected accelerometer readings to difference of their time tags
AC	V(3)		M50	Sensed acceleration (local variable used in AVERAGE_G_INTEGRATOR)
ALT	S	0		Attitude of Shuttle above reference ellipsoid
ANG_MOM	V(3)	0	EF	Shuttle's angular momentum vector
ASC_NODE	S	0		Longitude of the ascending node for the Shuttle orbit
COMP_MODE	CHAR	"CURRENT"		Indicates whether computations are to be performed for the Shuttle state at the current time or at a future time.
DEG_PER_RAD	S	(I LOAD)		Radian to degree conversion factor on
DO_PREDICT	BIT	OFF		Flag which indicates whether or not computations have been completed when "future" parameters are requested
DT_IMU	S			State vector average-G integration time step
DT_PREDICT	S	I LOAD		Integration step size
DTIME	S			Step size for state vector advancement (local variable used in AVERAGE_G_INTEGRATOR)

ORIGINAL PAGE IS OF POOR QUALITY

APPENDIX D VARIABLE LIST (Continued)

VARIABLE NAME	DATA TYPE	INITIAL VALUE	COORD FRAME	VARIABLE DESCRIPTION
EARTH_MU	S	I LOAD		Earth's gravitational constant
EVENT 60A	BIT	OFF		Transition from MM201 to OPS-8 event flag
EVENT 60	BIT	OFF		Transition to MM201 from MM106 event flag
EVENT 61	BIT	OFF		Transition to MM201 from MM301 event flag
EVENT 66	BIT	OFF		Transition to MM213 from MM201 event flag
EVENT 67	BIT	OFF		Transition to MM202 from 201 event flag
EVENT 69	BIT	OFF		Guidance initiate event flag
EVENT 73	BIT	OFF		Transition to MM201 from M202 event flag
EVENT 74	BIT	OFF		Transition to MM211 from MM106 event flag
EVENT 76	BIT	OFF		Transition to MM212 from MM211 event flag
EVENT 78	BIT	OFF		Transition to MM211 from MM212 event flag
EVENT 80	BIT	OFF		Transition to MM201 from MM213 event flag
EVENT 82	BIT	OFF		Transition to MM213 from MM211 event flag
EVENT 84	BIT	OFF		Transition to MM201 from OPS-00 event
FILT_UPDATE	BIT			Flag indicating the availability of a filter updated state

VARIABLE NAME	DATA TYPE	INITIAL VALUE	COORD FRAME	VARIABLE DESCRIPTION
GR	V(3)		M50	Gravitational acceleration (local variable used in AVERAGE_G_INTEGRATOR)
GR1	V(3)		M50	Gravitational acceleration (local variable used in AVERAGE_G_INTEGRATOR)
LAT_GEOD	S	0	EF	Geodetic latitude of the Shuttle sub-vehicle point
LONG	S	0	EF	Longitude of Shuttle sub-vehicle point
M_TEMP_TXPOS	M(9)	0		Transformation matrix from M50 to earth-fixed coordinates
NAUTMI_PER_FT	S	I LOAD		Feet to nautical mile conversion factor
R_AV	V(3)		M50	Position vestor (local variable used in AVERAGE_G_INTEGRATOR)
R_AVGG	V(3)		M50	Current orbiter position vector updated by user parameter propagator
R_COMP	V(3)	0	M50	Orbiter position vector at either the current time or a future time.
R_EF	V(3)	0	EF	Orbiter position vector in earth-fixed corrdinates
R_RESET	V(3)		M50	Copy of filter updated orbiter position vector for user parameter propagator reset

APPENDIX D VARIABLE LIST (Continued)

VARIABLE NAME	DATA TYPE	INITIAL VALUE	COORD FRAME	VARIABLE DESCRIPTION
R_TV_RESET	V(3)		M50	Copy of filter updated target position vector for user parameter propagator reset
REND_NAV_FLAG	BIT	OFF		Flag indicating whether rendezvous navigation is active (ON), or whether onorbit navigation is active (OFF)
R_TARGET	V(3)		M50	Position vector of the target vehicle, updated by the user parameters propagator
T_COMP	S	0		Time tag corresponding to R_COMP and V_COMP
T_IMU	S			Current time tag
T_PREDICT	S	0		Time for which future orbital parameters are to be computed
T_RESET	S			Copy of time tag of filter update of state vectors for user parameter propagator reset
T_STATE	S	0		Time tag for current user parameter state vector
USE_IMU_DATE	BIT	OFF		Flag indicating IMU data are to be used in integration (ON)
V_AV	V(3)		M50	Velocity vector (local variable used in AVERAGE_G_INTEGRATOR)
V_AVGG	V(3)		M50	Velocity vector of orbiter, updated by the user parameters propagator

APPENDIX D VARIABLE LIST (Continued)

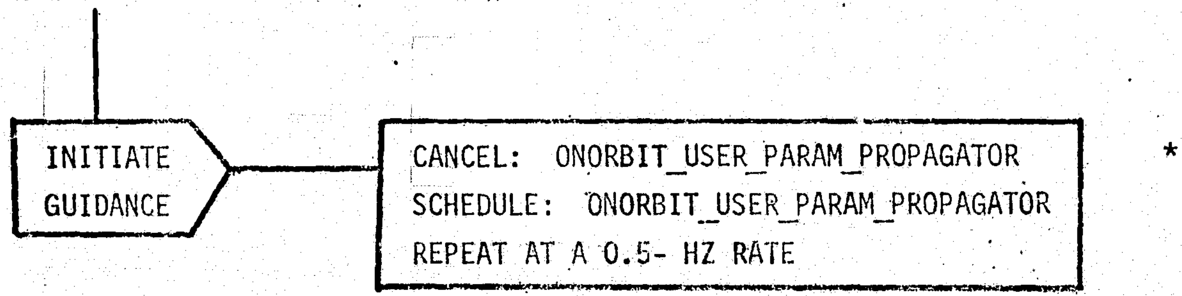
VARIABLE NAME	DATA TYPE	INITIAL VALUE	COORD FRAME	VARIABLE DESCRIPTION
V_COMP	V(3)	0	M50	Orbiter velocity vector at either the current time or a future time
V_EF	V(3)	0	EF	Orbiter velocity vector in earth-fixed coordinates
V_IMU_CURRENT	V(3)		M50	Current selected accumulated IMU velocity
V_IMU_OLD	V(3)		M50	Previous accumulated IMU velocity
V_IMU_RESET	V(3)		M50	Copy of IMU accumulated sensed velocity for user parameter prodagator reset
V_RESET	V(3)		M50	Copy of filter updated orbiter velocity vector for user parameter propagator reset
V_TARGET	V(3)		M50	Velocity vector of the target vehicle, updated by the user parameters propagator
V_TV_RESET	V(3)		M50	Copy of filter updated target velocity vector for user parameter propagator reset

ONORBIT_REND_UPP_SEQ

TRANSITION TO OPS-2 FROM (OPS-1, OPS-3, or OPS-00	SCHEDULE: ONORBIT_REND_USER_PARAM_ STATE_ PROP ON OPS_2_INITIALIZE COMPLETE REPEAT AT A 0.5 HZ RATE SCHEDULE: NAV_MONITOR_SUPPORT REPEAT AT A 0.5 HZ RATE
TRANSITION TO 201 FROM OPS-8	SCHEDULE: NAV_MONITOR_SUPPORT REPEAT AT A 0.5 HZ RATE
TRANSITION TO OPS-8 FROM 201	CANCEL: NAV_MONITOR_SUPPORT
TRANSITION FROM 201 to (202 or 213)	CANCEL: NAV_MONITOR_SUPPORT
TRANSITION FROM 211 TO (212 or 213)	CANCEL: NAV_MONITOR_SUPPORT
TRANSITION TO 201 FROM (202 or 213)	SCHEDULE: NAV_MONITOR_SUPPORT REPEAT AT A 0.5 HZ RATE
TRANSITION TO 211 FROM 212	SCHEDULE: NAV_MONITOR_SUPPORT REPEAT AT A 0.5 HZ RATE

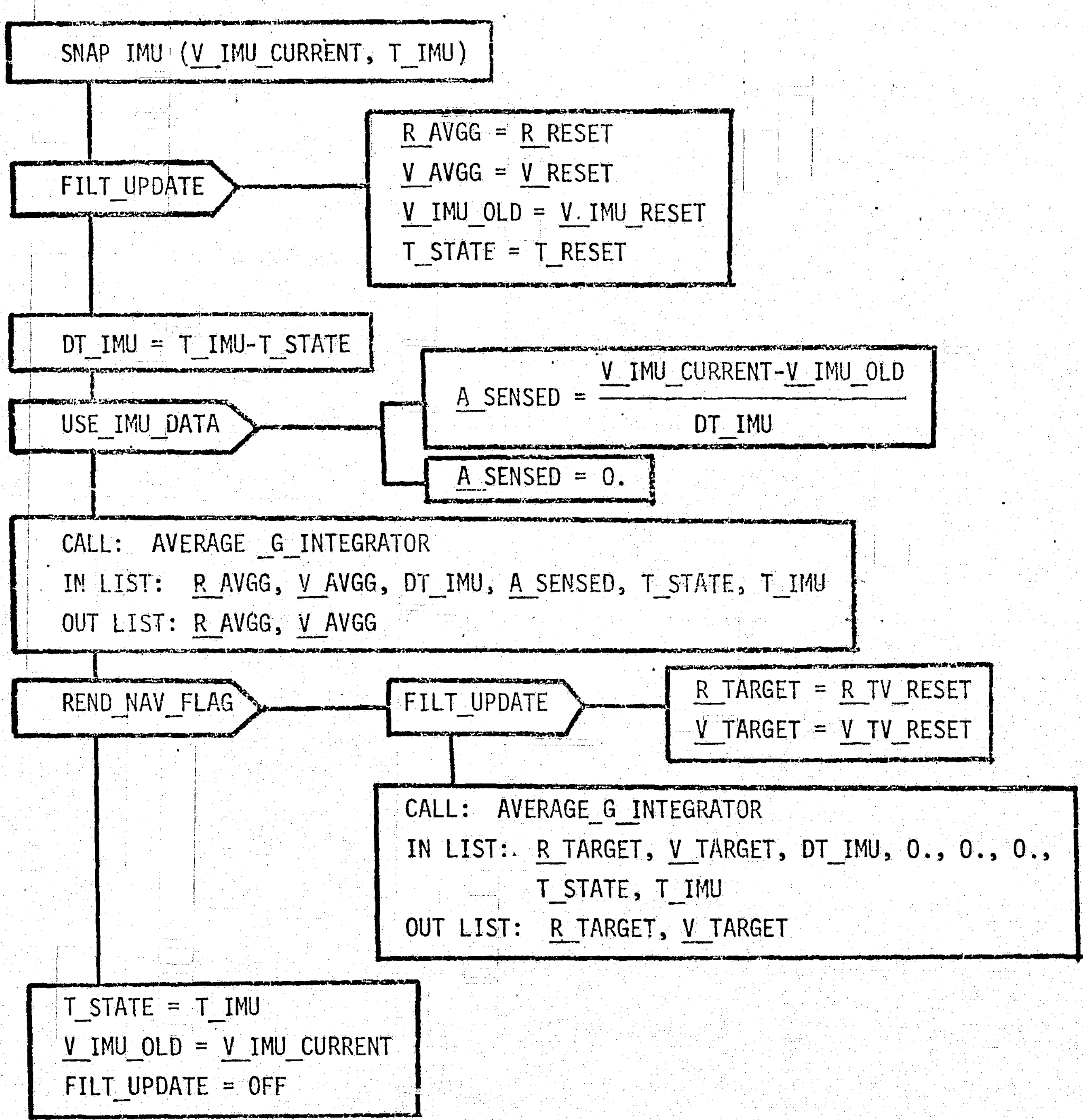
(cont)

ONORBIT_REND_UPP_SEQ (concluded)



* The purpose of this cancel and reschedule is to synchronize this module with the executions of onorbit guidance which is to begin computations at this time.

ONORBIT_REND_USER_PARAM_STATE_PROP



AVERAGE_G_INTEGRATOR

IN LIST: R_AV, V_AV, DTIME, AC, T_STATE, T_IMU

OUT LIST: R_AV, V_AV

```
GR = ACCEL_PERT_ONORBIT (2, 0, 0, 0, 0, R_AV, V_AV, T_STATE)
GR = GR - EARTH_MU R_AV/|R_AV|^3
R_AV = R_AV + DTIME [V_AV + .5 DTIME (AC + GR)]
GR1 = ACCEL_PERT_ONORBIT (2, 0, 0, 0, 0, R_AV. V_AV, T_IMU)
GR1 = GR1 - EARTH_MU R_AV/|R_AV|^3
V_AV = V_AV + DTIME [AC + .5(GR + GR1)]
```

NAV_MONITOR_SUPPORT

DO_PREDICT = ON
OR
COMP_MODE =
CURRENT

COMP_MODE =
CURRENT

R_COMP = R_AVGG
V_COMP = V_AVGG
T_COMP = T_STATE

CALL: ONORBIT_PREDICT
IN LIST: 2,0,1,0,2, DT_PREDICT,
R_AVGG, V_AVGG, T_
STATE, T_PREDICT
OUT LIST: R_COMP, V_COMP

T_COMP = T_PREDICT
DO_PREDICT = OFF

M_TEMP_TXPOS = EARTH_FIXED_
TO_M50_COORD (T_COMP)
R_EF = M_TEMP_TXPOS R_COMP
V_EF = M_TEMP_TXPOS V_COMP

CALL: EF_TO_GEODETIC
IN LIST: R_EF
OUT LIST: LAT_GEOD, LONG, ALT

ALTITUDE = ALT_NAUT_MI_PER_FT
LATITUDE = LAT_GEOD DEG_PER_RAD
LONGITUDE = LONG DEG_PER_RAD
ANG_MOM = R_EF X V_EF
ASC_NODE = ARCTAN2(ANG_MOM$_1$,
-ANG_MOM$_2$) DEG_PER_RAD